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GEOPHYSICS

A Journal of General and Applied Geophysics

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The Society of Exploration Geophysicists

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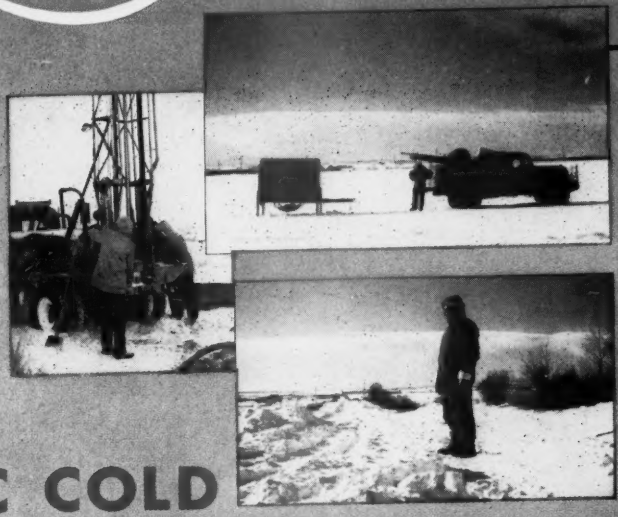

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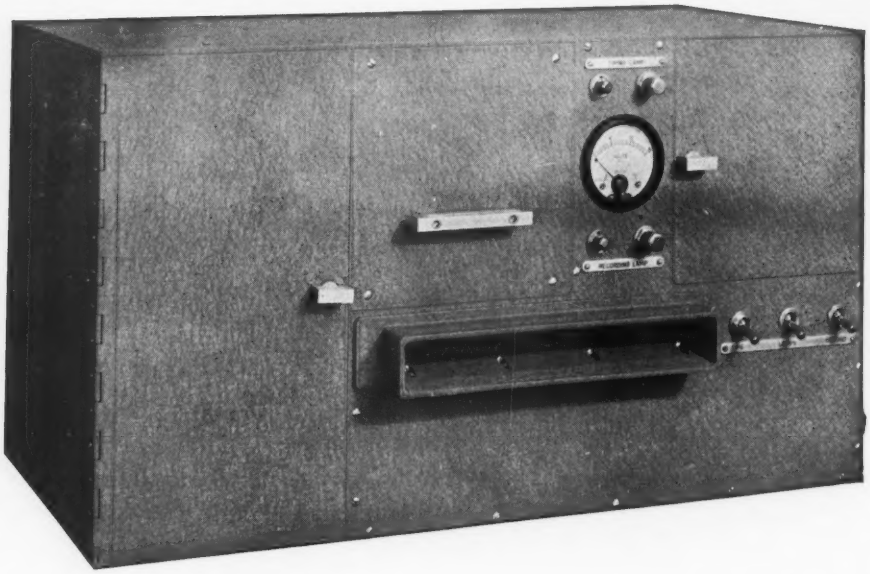

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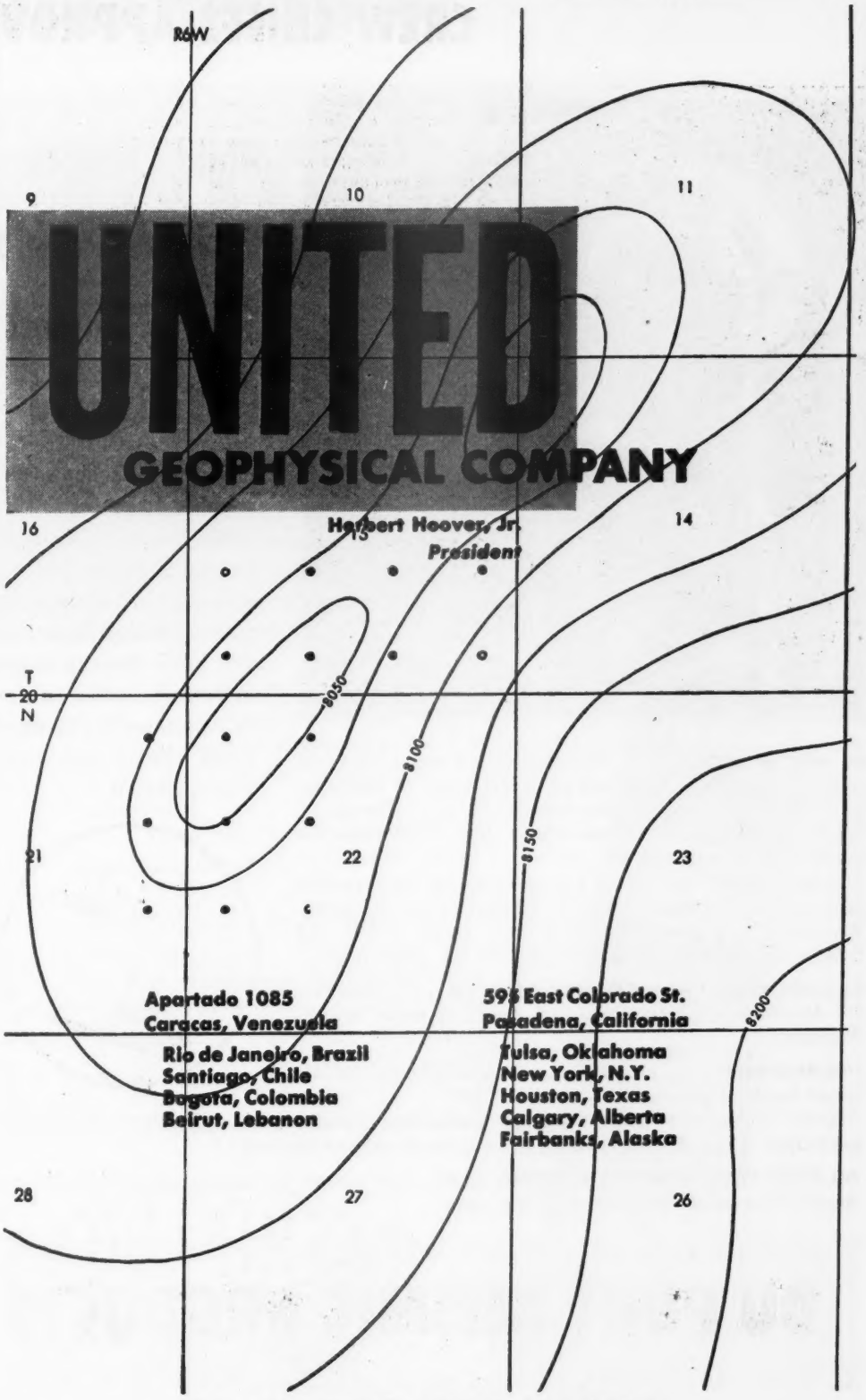

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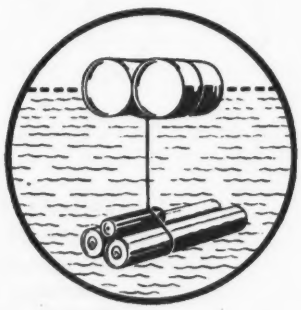

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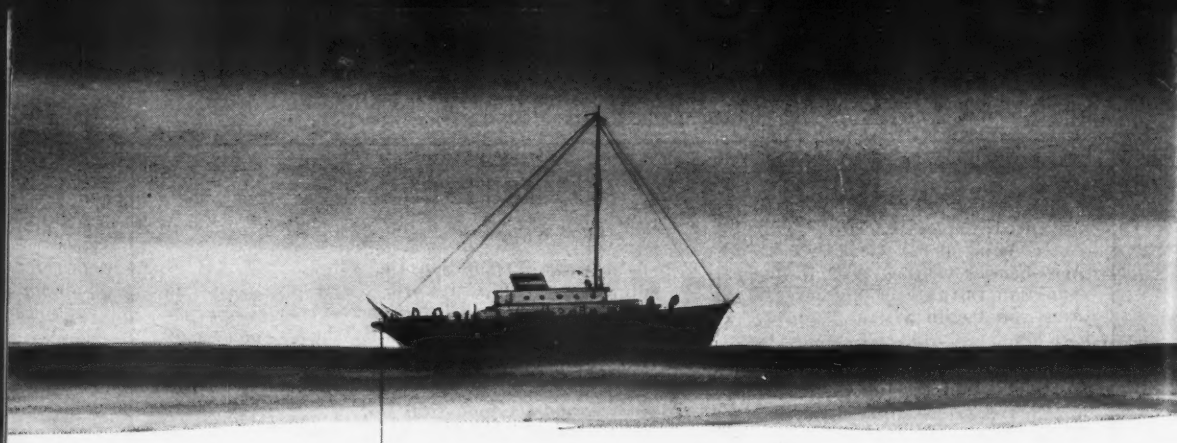

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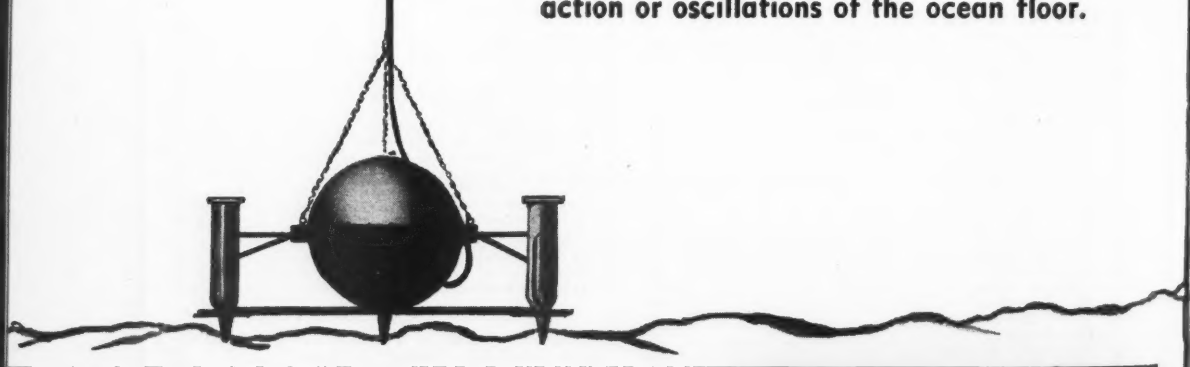

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VOLUME XIV APRIL, 1949 NUMBER 2

GEOPHYSICS

A Journal of General and Applied Geophysics

GEOPHYSICAL DEVELOPMENTS IN EUROPE DURING THE WAR*

RAOUL VAJK†

Intensive geophysical activity took place in many of the European countries during the war. However, as corresponding literature is inadequate and hardly accessible, not much was published here on this subject. The writer has compiled some information obtained from various sources and, though they are still incomplete, believes that the most important geophysical surveys made in Europe during the war are covered by the following data.

GERMANY

Considerable geophysical exploration had already been carried out in Germany before the war. Most of northern Germany, the Alpine foreland in Bavaria (southernmost Germany), and the whole Rhine Valley Graben were covered by magnetometer and gravity-meter surveys. The main oil regions in Mecklenburg and Hanover, west and central Schleswig-Holstein, the northwestern part of Oldenburg and the Rhine Valley Graben were surveyed by torsion balance. Refraction seismograph surveys were made in the northern part of the north German oil district and some reflection seismograph investigations were made on the flanks of salt domes. The seismograph exploration in Germany was handicapped by the Mintrop patent. Only after 1937, when it expired, was permission given to import seismographs from the United States which gave an impulse to the application of this method in Germany.

From 1935 to 1938 four oil fields were discovered by gravity surveys and two by seismograph surveys. During the same period three oil fields were found by surface geology and two by wildcat drilling.

Since 1939 the torsion balance has been largely replaced by the gravity meter. In that year the Askania put the Graf gravity meter on the market and a few years later, a second, smaller type of the same gravity meter was developed.

Additional gravity-meter work, filling in gaps and detailing previous surveys,

* Manuscript received by the Editor, December 20, 1948.

† Standard Oil Co. (N.J.), New York.

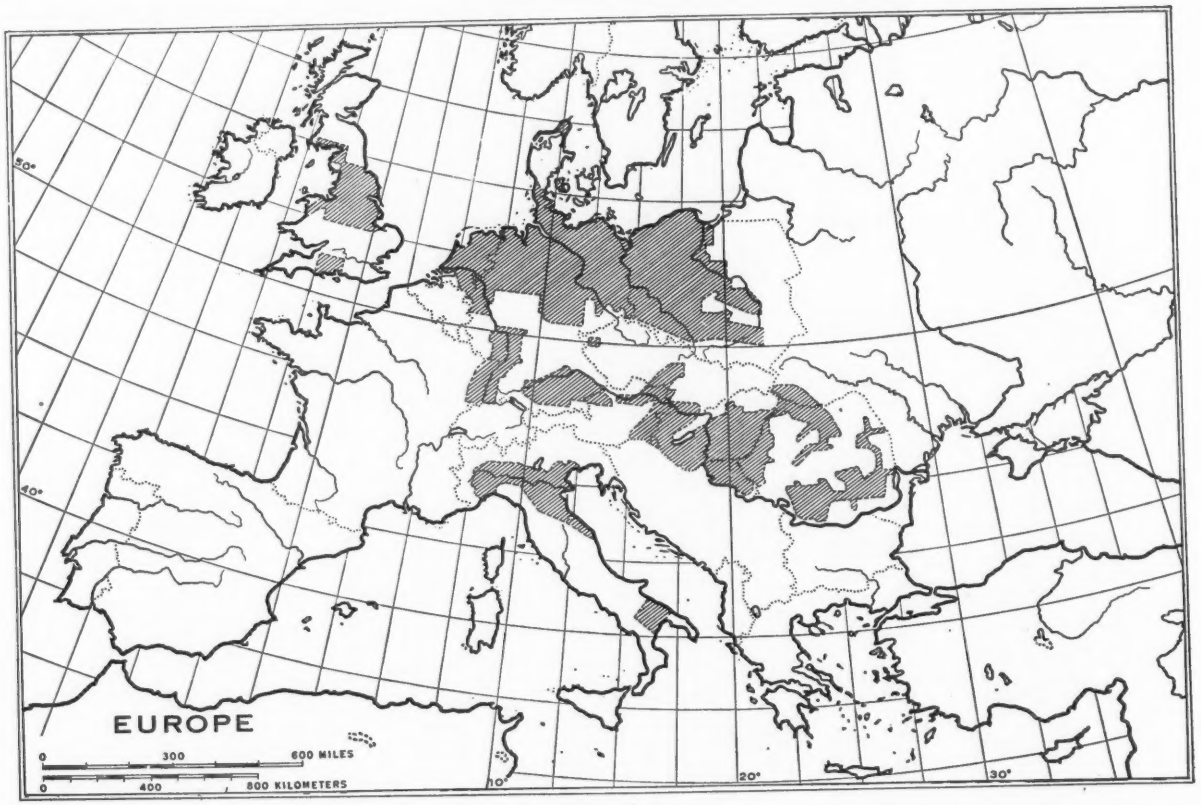

FIG. 1. Areas covered by gravity-meter and torsion-balance surveys as of 1945. This map is not complete, as, for instance, no information could be obtained on gravity surveys made in southwestern France, in small, scattered areas in Sweden, and over large areas in Russia.

was done in Mecklenburg (1939, 1940), in the Rhine Valley Graben (1941) and in the area between the Harz Mountains and the "Thüringer Wald" (1940, 1941). Some detailed surveys were made on the flanks of salt domes. Four gravity meters were engaged in these surveys.

Two or three torsion-balance parties (six to eight instruments) surveyed Oldenburg, west and central Schleswig-Holstein, the upper Rhine Valley Graben, large parts of the Bavarian Alpine foreland and the oil district between the Elbe and Weser Rivers between Hanover and Hamburg.

Two seismograph crews covered almost the entire north German oil region by a refraction seismograph survey and detailed more than fifty structures by line shooting. Five or seven reflection-seismograph parties investigated the flanks of salt domes.

One or two geolectrical parties were working in Germany during the war. They surveyed mostly the structures of oil fields, attempting to determine the depth of the salt and other electrically favorable key horizons. The results were, in general, poor, though in some cases key horizons (oil impregnated chalk, bituminous beds) were successfully traced.

No magnetometer survey was made in Germany during the war.

As a result of geophysical exploration, seven oil fields were discovered during the war. Four of them (Ehra, in 1939; Thoren, 1941; Etzel, 1942; and Calberlah, 1945) were discovered by gravity surveys and three (Lingen, 1942; Emlichheim and Georgsdorf, 1943) by seismic surveys. During the same period five oil fields were discovered by wildcat drilling.

The outlook for the discovery of new oil fields in Germany was limited and, therefore, due to the desperate need for more and more oil, assiduous geophysical exploration was carried out in the German-occupied territories. The primary aim of the Reichsamt was to secure a regional picture of the distribution of structures which would guide the acquisition of concessions for exploration.

NETHERLANDS

The geophysical exploration activities of the B.P.M., temporarily suspended in 1938, were resumed in October 1941 by a joint operation between the B.P.M. and the German firm, Elverath, as a consequence of an agreement forced upon B.P.M. by its German custodian during the occupation. A summary of the exploration work accomplished from October 1941 to May 1945 is given below.

Gravity Survey.—The eight provinces north of the Rhine, with the exception of the islands, were covered with a good network by three gravity-meter parties (Thyssen and Graf instruments). This survey was terminated in August 1944. In addition to the gravity-meter survey, about 8,500 torsion-balance stations were made by seven torsion balances, mostly in the area east of the River Ijssel.

Seismic Refraction Survey.—The eastern part of the Province of Overijssel, the southern part of the Province of Drente and small areas westward from the Ijssel River were investigated by short refraction profiles totaling about 1,400

kilometers. The aim of this survey was to obtain structural information in connection with the core drilling program and to investigate the thickness of the Tertiary sediments.

Seismic Reflection Survey.—From the middle of 1943 to the end of 1944 eighty-five kilometers of reflection profiles were made on the Schoonebeek structure and in the southeast part of Drente Province.

Magnetic Survey.—A regional survey containing about three hundred magnetometer stations was made in 1944 in Drente, Groningen, and Friesland Provinces.

One important result of the geophysical surveys was the discovery of the Schoonebeek oil field in May, 1943 by the second well. It should, however, be stressed that indications regarding the existence of a favorable oil structure here were already known from geophysical work and core drilling carried out by B.P.M. before the war.

GERMAN-OCCUPIED RUSSIA

After the German troops invaded Russia, a regional gravity-meter exploration program was carried out in the salt-dome region in the Ukraine. During the summers of 1942 and 1943, three refraction seismograph parties, four reflection seismograph parties, five gravity-meter and seven torsion-balance parties were working in the Ukraine, mostly in the Rommy area. A magnetometer party surveyed a considerable part of the immense Ukraine depression.

AUSTRIA

Most of the gravity and refraction-seismograph work was made by the Prakla and by the Seismos. The magnetic survey was useful in locating igneous rocks and in the study of the crystalline basement, especially at the eastern end of the Bohemian massive.

The limited use of the reflection seismic method is partly due to the lack of good reflecting horizons and to the out-of-date equipment. However, later, in the Vienna Basin and in Czechoslovakia, the surveys were more successful.

In 1940 one magnetometer party surveyed the Outer Alpine Vienna Basin and the Pannonian Basin. From 1939 to 1944 one to four refraction seismograph parties were working in the North Alpine Basin, Outer Alpine Vienna Basin, Vienna Basin, and the Graz Basin. From 1939 to 1945 one to three reflection seismograph parties carried out some surveys in the Vienna Basin and in the Outer Alpine Vienna Basin.

In 1939 and 1940 there were five parties, in 1941, four parties and in 1942, three parties engaged in torsion-balance surveys in the Outer Alpine Basin, Vienna Basin, North Alpine Basin, Leitha Mountains area and the Pannonian Basin. Gravity-meter surveys were made from 1939 to 1944 by two to four parties and in 1945 by one to three parties in the Vienna Basin, Graz Basin, North Alpine Basin, Outer Alpine Basin and the Pannonian Basin.

CZECHOSLOVAKIA

In Czechoslovakia a torsion-balance party was in operation in the Pannonian Basin from 1939 to 1941 and another in Slovakia in 1940. In addition, one or two gravity-meter parties made some surveys from 1939 to 1944. From 1940 to 1945 a seismic refraction party, from 1940 to 1941 and from 1943 to 1945 a seismic reflection party of the Prakla made a survey in Slovakia and in Moravia.

A magnetometer party did some work in 1940 in Moravia and two to three parties were working in Slovakia during 1943 and 1944.

HUNGARY

In Hungary the Maort* operated a torsion-balance party and a gravity-meter party on its concession covering Transdanubia (southwest part of Hungary) from 1939 to 1944, detailing previously found anomalies and filling out gaps between formerly surveyed areas. A reflection seismograph party was engaged in checking gravity anomalies during 1939 and 1940. From 1939 to 1944 a magnetometer party carried out alternately detailed vertical and horizontal magnetometer surveys in the above area, investigating gravity prospects for possible volcanic intrusions.

In the Great Hungarian Plains geophysical exploration was done mostly in the southern half of the Plains covered by the Manat (Hungarian-German Oil Co.) concession. The entire concession was practically covered by two gravity-meter parties from 1941 to 1944, and the gaps of previous torsion-balance surveys were covered by one or two torsion-balance parties.

From 1940 to 1944 one to three "Seismos" seismograph parties carried out reflection and refraction seismograph surveys in the Manat concession, and a few reflection and refraction seismograph traverses were made by the Eötvös Institute in the southern part of this area.

From 1940 to 1943 two torsion-balance parties of the Eötvös Institute were working for the Hungarian Government in those parts of Transylvania which were returned to Hungary temporarily during the war.

From December 1942 to September 1943 a gravity-meter party surveyed northeastern Hungary in the vicinity of Munkács, Beregszász and Huszt, which had been temporarily returned to Hungary. Three thousand four hundred and twenty-four gravity-meter stations were made in this rather hilly area. This work was done by the Hungarian-Italian Oil Co., which obtained an oil concession for this area from the Hungarian Government.

YUGOSLAVIA

A German gravity-meter party surveyed the area adjoining the Lovászi and Ujfalu (Hungary) oil fields in Yugoslavia. Locally some other methods were also used, probably seismic and magnetic.

* Magyar Amerikai Olajipari r.t. is owned by the European Gas & Electric Co. and was taken over by the Hungarian Government at the beginning of hostilities.

RUMANIA

The information obtained on the geophysical activities in Rumania are probably not quite complete.

Gravity Survey.—In 1940 a gravity-meter survey was made in the Bacau region on the Tetcani-Scorteni structure and in Moldova as far north as Pascani. In 1941 some work was done in the Banat (the area between the Mures, Tisza, and Danube Rivers and the Transylvanian Mountains) western Rumania, and some additional gravity-meter work was made in the vicinity of Prahova, in the vicinity of Buzau and in Moldova (northeastern Rumania). Finally the area between Braila and Ramnicul-Sarat and between Orlea and Buzau, and the North Oltenia district were surveyed.

In 1942 about 2,500 gravity-meter stations were made in north Oltenia in the Banat and between Baicoi and Targoviste. During the same year the Kontinentale A.G. made about 900 torsion-balance stations in the vicinity of Arad.

During 1943 about 5,600 gravity-meter stations were observed in Molodva and in the vicinity of Braila and Galati. In the first half of 1944 about 450 gravity-meter stations were made between Bacau and Vaslui, and in the vicinity of Campulung.

Magnetometer Survey.—A magnetometer survey consisting of about 1,700 stations was carried out in the Banat area, western Rumania.

Seismic Survey.—At the end of 1940 and in the first part of 1941 a reconnaissance reflection seismograph survey was made in the Craiova region and some detailed work in the Prahova area. From 1942 to 1944 most of the reflection work was done in the Banat (western Rumania). In the second part of 1943 and in the first part of 1944 some reflection shooting was done in the vicinity of Campulung and in the Chisineu-Criz area.

The reflection seismograph survey in Banat was supplemented by some refraction work from the end of 1942 to the first part of 1944 with a few months interruption for making a few refraction profiles in the Chisineu-Criz area.

Soil-Gas Analysis.—Some experimental soil-gas analysis survey was made in 1940 in the Prahova area and in the vicinity of Craiova.

POLAND

Regional gravity and magnetometer surveys were made in the Flysch Carpathian and in the Carpathian foreland. From 1943 to 1944 one magnetometer party, and from 1940 to 1944 two to five gravity-meter parties and two to five torsion-balance parties were working in this area. These regional surveys were supplemented by local refraction seismograph (in 1941, three months; in 1942, two months; and in 1943, six months) and reflection seismograph surveys (in 1943, four months).

ITALY

In Italy only the Azienda Generale Italiana Petroli (AGIP) and the Societa Petrolifera Italiana (SPI) were engaged in geophysical exploration during the war.

The AGIP carried out a large-scale, essentially regional, reflection seismic ex-

ploration with one crew up to September 1943. Afterward the activity was reduced, and finally in June, 1944 was terminated because of the war. Approximately 4,800 km² were surveyed in the Piacenza-Lodi district and in the area around Parma, Reggio, and Modena with approximately 2,600 shotpoints. A gravimetric survey was carried out from January 1941 to July 1943 with a Graf (Askania) gravity meter in the Apulia and Lucania regions (Bradanic Trough and Munga Range, southernmost Italy). This survey, containing approximately 1,300 gravity-meter stations, covered an area of about 8,500 km².

The SPI* completed about 11,500 gravity-meter stations in an area of approximately 47,000 km². From 1940 to 1942 the survey was made by two gravity-meter parties; from 1942 on, only one party was working in Italy, as the second gravity-meter party was sent to Hungary to survey the Hungarian-Italian Oil Company's (AGIP) concession.

A magnetometer survey consisting of about 1,800 magnetometer stations and covering approximately 5,600 km² was made from 1940 to 1942.

SWITZERLAND

Some magnetometer work was carried out in western Switzerland and an electrical method was used for outlining the course of ground water. A new geophysical department has been instituted in the Federal Technical High School at Zürich (Professor Gassmann) and courses on geophysics are given at the University of Geneva (Professor Poldini).

ENGLAND

The data obtained on the geophysical activities in England during the war are summarized as follows:

Year	Method	Area
1939	Magnetometer	Mithlothian, Scotland
	Gravity meter	East Midlands area
	Seismograph (reflection)	Northeast Yorkshire
	Geochemical	Midlothian, Scotland
1940	Gravity meter	Westmoreland
	Seismograph (refraction)	East Midlands area
	Geochemical	East Midlands area
1941	Seismograph (refraction)	Notts
	Geochemical	West Lancashire
1942	Seismograph (refraction)	East Midlands
	Geochemical	East Midlands
1943	Seismograph (refraction)	West Lancashire
	Seismograph (reflection)	East Midlands area
1944	Seismic (reflection)	East Midlands area
1945	Magnetometer	East Midlands area
	Seismograph (refraction)	East Midlands area
	Gravity meter	Hampshire Basin
1946	Gravity meter	Hampshire Basin

* The SPI was taken over by the Italian Government at the beginning of the war.

FRANCE

From 1941 to 1942 one to three gravity-meter parties, from 1941 to 1943 two to four torsion-balance parties and in 1942 one refraction seismograph party (four months), one reflection seismograph party (two months) and one magnetic party were working in Alsace.

In the Aquitanian Basin in southern France and in the forelands of the Pyrenees Mountains electrical (telluric method) and gravity surveys were made and the indications thus found were checked by a detailed seismograph survey. Several geophysical prospects were outlined in the vicinity of the St. Marcet gas field.

ACKNOWLEDGMENT

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A. E. Gunther, "German Oil Industry. Exploration," *B.I.O.S. Final Report No. 1011*, Item No. 3, "Oil Field Investigation. The War Development of the German Crude Oil Industry 1939–1945," Part II, Section I. London, 1947.

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A DISCUSSION OF STEEP-DIP SEISMIC COMPUTING METHODS*

R. B. RICE†

ABSTRACT

This paper presents a comparison of the results obtained by the application of several standard computing techniques to the computation of steep-dip seismic data. Formulas for the horizontal displacements and depths of reflection points are derived for the various methods, assuming velocity to be a parabolic function of depth, and the results obtained for a typical velocity function over a wide range of reflection and stepout times are compared graphically. In addition, the overall effect of applying these methods to the computation of a specific steep-dip asymmetric structural profile is studied.

INTRODUCTION

There are a considerable number of reflection seismograph computing methods in use at the present time. These methods may be classified in several different ways. They may be classified according to the basic assumptions made in deriving them as Alcock[1] has done. Or they may be classified according to the results they produce for given "stepout" and "reflection" times, that is, according to the magnitude of the displacements and depths of the reflection points obtained. Some of the methods involve the assumption of seismic paths which can and do have physical significance in certain areas. Others employ mathematical formulas which are deemed to produce correct results but which in themselves have no apparent physical meaning.

The purpose of this paper is to compare several standard computing techniques commonly used in steep-dip areas on the basis of the horizontal displacements and depths of reflection points they produce, assuming a typical parabolic increase of velocity with depth, and to show the overall effect of applying these methods to the computation of one specific steep-dip asymmetric structural profile.

No single computing method can be expected to give valid results in all areas because of the fact that certain assumptions in regard to velocity must be made before any method can be derived. Although Alcock[2] has discussed most of these assumptions in detail, they will be listed here again for emphasis and for convenience of reference.

A_1. It is universally assumed that there is a one-to-one correspondence between velocity discontinuities and stratification discontinuities in the subsurface.

* Phillips Petroleum Company, Research Department, Report No. 676-48R. Manuscript received by the Editor, November 8, 1948.

† Phillips Petroleum Company, Bartlesville, Oklahoma.

[1] E. D. Alcock, "Selection of Computational Methods for Seismic Paths," *Geophysics*, VIII (July, 1943), 297–307.

[2] E. D. Alcock, *loc. cit.*

A_2. Some assumption must be made as to the attitude of the iso-velocity layers between the shotpoint and the point of reflection. This is the main assumption which distinguishes one computing method from another. The types of assumptions made under this heading may be classified as follows:

(1) The iso-velocity layers are assumed to be horizontal (See Fig. 1-*A*). This hypothesis forms the basis of the so-called curved-path methods, in which the path of a seismic wave incident upon the boundary of two iso-velocity layers is assumed to be bent in accordance with Snell's law.

(2) The iso-velocity layers are assumed to be parallel to the reflecting horizon (Fig. 1-*B*). This assumption coincides with A_2-1 when the reflecting horizon is horizontal, and it leads to a computing method in which the angle of dip, α, is given by

$$\sin \alpha = v_o \Delta t / s, \tag{1}$$

where v_o is the interval velocity at the surface between two shotpoints, Δt is the stepout time between the two normal one-way paths from the shotpoints to the reflecting horizon and s is the distance between the shotpoints. Since v_o is the minimum value for the velocity for a given Δt and s, this method gives a minimum value for α and hence a minimum value for the displacement and a maximum value for the depth of the reflection point.

(3) Some configuration in between those of Figures 1-*A* and 1-*B* is assumed. Obviously there are an indefinite number of such patterns possible. Figures 1-*C* and 1-*D* show two possible types which occur frequently, although the latter is actually merely a combination of those of *A* and *B*.

Also, the pattern of *C*, in which there is a gradual increase in dip of the iso-velocity layers down to the reflecting horizon, might be reversed, that is, the iso-velocity layers could be parallel to the reflecting horizon at the surface and then gradually approach a horizontal alignment with increase in depth. In fact, although data are scarce, it is certain that any local perturbations or dipping of iso-velocity strata disappear if great enough depths are considered. In this regard Widess,[3] in summarizing the work of Haskell,[4] Weatherby and Faust,[5] Birch and Bancroft,[6,7] and Gutenberg,[8] reported that in the shallower zones overburden is mainly responsible for the increase of velocity with depth, the figure given by

[3] M. B. Widess, "Effect of Surface Topography on Seismic Mapping," *Geophysics*, XI (July, 1946), 302–372.

[4] N. A. Haskell, "The Relation Between Depth, Lithology and Seismic Wave Velocity in Tertiary Sandstones and Shales," *Geophysics*, VI (October, 1941), 318–326.

[5] B. B. Weatherby and L. Y. Faust, "Influence of Geological Factors on Longitudinal Seismic Velocities," *Bull. A.A.P.G.*, *19* (January, 1935), 1–8.

[6] F. Birch and D. Bancroft, "The Effect of Pressure on the Rigidity of Rocks," *Jour. of Geol.*, *46* (Jan.–Feb., 1938), 59–87; Pt. 2, *46* (Feb.–March, 1938), 113–141.

[7] F. Birch and D. Bancroft, "New Measurements of the Rigidity of Rocks at High Pressure," *Jour. of Geol.*, *48* (Oct.–Nov., 1940), 752–766.

[8] Beno Gutenberg, "Variation in Physical Properties Within the Earth's Crustal Layer," *Am. Jour. of Sci.*, *234A*, Daly Vol. (1945), 285–312.

Haskell for California wells up to 13,000 feet being 78 percent. However, this effect decreases rapidly at depths over 10,000 feet. In steep-dip areas where high-velocity beds outcrop, first-break times on seismic records give ample evidence that near-surface iso-velocity layers are far from being horizontal and do in many cases more nearly approach the conditions shown in Figure 1-*B* than any other until the above-mentioned leveling off effect begins to take hold.

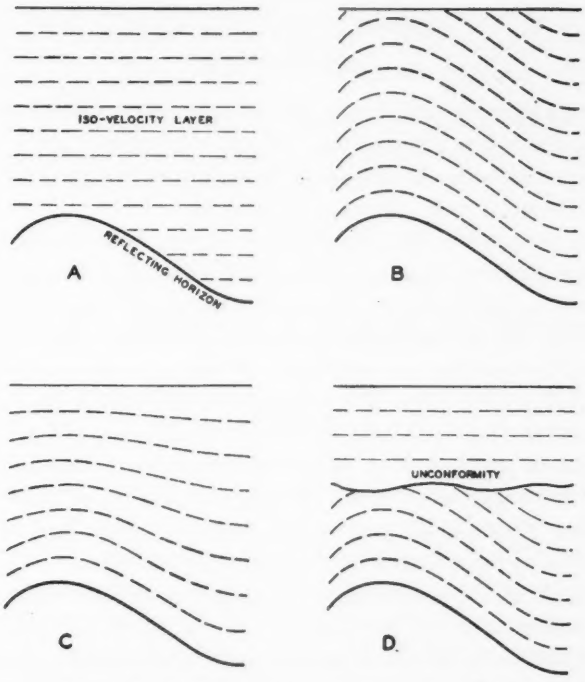


FIG. 1. Possible types of iso-velocity configurations.

A_3. In many methods it is assumed that the seismic paths are straight. From a physical standpoint, this assumption is compatible with only one of the assumptions in A_2, namely A_2-2 (except in the special case when the reflecting horizons are horizontal), and in this case some contradiction arises when the incident and reflected wave paths are not coincident. However, the assumption is made in the interest of simplification.

A computing method (which we shall term the "straight-path" method) in which this physical inconsistency is ignored and assumptions A_2-1 and A_3 postulated leads to the following formula for the angle of dip:

$$\sin \alpha = v_i \Delta t / s, \tag{2}$$

where α, Δt, s have the same meaning as in equation (1) and v_i is the interval velocity between the two points of reflection. Since v_i is a maximum velocity for a

given reflection time, such a method, in contradistinction to the one defined by equation (1), gives a maximum value for the dip and displacement and a minimum value for the depth. In fact, as will be shown later, this method produces displacements which are greater than those obtainable by curved-path procedures.

If assumption A_3 and a configuration of the type of Figure 1-*C* are postulated, a method which employs the following formula for the angle of dip can be derived:

$$\sin \alpha = \bar{v}\Delta t/s, \tag{3}$$

where α, Δt, and s have the same meaning as before and $\bar{v}$ is the average velocity over the paths. Since $\bar{v}$ is intermediate in value between v_o and v_i, the angle of dip, displacements and depths obtained by such a method will lie between those obtained using formulas in equations (1) and (2).

A_4. Another assumption commonly made is that the velocity-depth gradient is the same over a given area. In areas of relatively flat dip, this assumption is justified because it quite closely approximates actual conditions. In steep-dip areas, however, it is made only because velocity information is so meager that there is nothing else one can do. Obviously, such an assumption is in contradiction to assumptions A_2-2 and A_2-3. The effect on final results obtained using a combination of these assumptions is to distort the final structural picture somewhat, although the lateral position of the highs is generally not affected.

A_5. An alternate assumption which is occasionally used is obtained by construing the word "depth" in A_4 to mean the "depth" measured along the path of reflection, that is, at right angles to the reflecting horizon.

This assumption is very seldom justified, but is used in what we shall refer to as the "depth-displacement" method in which reflection times are converted directly to "depths" by means of a time-depth curve and then resolved by the swinging arc method, which of course implies A_3 in addition. As will be illustrated later, this method produces even larger dips and displacements than the "maximum" values produced by the "straight-path" method based on relation in equation (2), and hence has no merit other than its simplicity.

A_6. In all computing methods it is assumed that the velocity of propagation is isotropic in every layer in which the velocity in one direction, say at right angles to the interface, is constant. Very little attention has been paid to this assumption in the literature. It is postulated in deriving the various methods in order to simplify the analytical analysis of an otherwise highly complex problem. However, it is important to keep this assumption in mind in comparing results obtained by different methods; for, even if every other assumption made is correct, asymmetry in the velocity can cause calculated displacements and depths to be in error.

For example, to give some idea of how a wave incident at an angle i upon the interface between two non-isotropic media may be refracted at various angles r,

let V_1, V_2 denote the velocities normal to the interface in the two media, V_1', V_2' the corresponding velocities parallel to the interface, and let

$$\begin{aligned} k_1 &= V_1'/V_1, \\ k_2 &= V_2'/V_2. \end{aligned} \tag{4}$$

Furthermore, assume that the velocities for any angle of traverse through the two media are given by

$$\begin{aligned} V_1^i &= V_1 + (V_1' - V_1) \sin i, \\ V_2^r &= V_2 + (V_2' - V_2) \sin r, \end{aligned} \tag{5}$$

respectively, where V_1^i, denotes the velocity in the first medium at the angle of incidence, i, and V_2^r, the velocity in the second medium at the refraction angle, r. These relations obviously satisfy the conditions

$$\begin{aligned} V_1^i &= V_1, \quad V_2^r = V_2 \quad \text{for} \quad i = 0, \quad r = 0 \\ V_1^i &= V_1', \quad V_2^r = V_2' \quad \text{for} \quad i = 90^\circ, \; r = 90^\circ. \end{aligned}$$

Substituting equation (4) in equation (5), and applying Snell's law, one obtains

$$\sin r = \frac{V_2 \sin i}{V_1(1 + (k_1 - 1) \sin i) - V_2(k_2 - 1) \sin i}, \tag{6}$$

which reduces to the usual form of Snell's law for isotropic media when $k_1 = k_2 = 1$.

Now if we take $V_1 = 9{,}500$ ft/sec, $V_2 = 10{,}000$ ft/sec and $i = 30^\circ$, then the angle of refraction commonly assumed for $k_1 = k_2 = 1$ would be $r = 31^\circ\ 45'$. However, if $k_1 = k_2 = 1.4$, $r = 32^\circ\ 8'$; or, if $k_1 = k_2 = 0.6$, $r = 31^\circ\ 23'$. If k_1 and k_2 are greater than unity but k_1 is greater than k_2, say $k_1 = 1.4$, $k_2 = 1.2$, then the ray is bent toward the normal ($r = 28^\circ\ 44'$). If the reverse is true, say $k_1 = 1.2$, $k_2 = 1.4$, then $r = 36^\circ\ 17'$ and the ray is bent considerably more away from the normal than in the isotropic case.

It is very difficult to estimate the amount of cumulative error due to such deviations from the isotropic case which may be present in the results obtained using a given computing method, for data are scarce. There is a great need for the compilation of a wealth of statistics on velocity asymmetry. In 1932 McCollum and Snell[9] reported an average figure of 1.4 for the ratio between the average velocity parallel to and normal to the bedding planes of Lorraine shales in Quebec. These results were in qualitative agreement with those obtained by Weatherby, Born and Harding[10] in 1933 for Arbuckle limestone, the ratio found by them being 1.3. However, even though it is probable that such qualitative results as these will be further substantiated in the future in similar experiments, it

[9] Burton McCollum and F. A. Snell, "Asymmetry of Sound Velocity in Stratified Formations," *Physics* (March, 1932), 72–83.

[10] B. B. Weatherby, W. T. Born, and R. L. Harding, "Granite and Limestone Velocity Determinations in Arbuckle Mountains, Okla.," *Bull. A.A.P.G., 18* (January, 1934), 106–118.

is still difficult to say what ratios should be assumed for paths which are in between those normal and parallel to the bedding planes; for it is possible that the average ratio may be close to unity for any path which cuts across many bedding planes. In other words, the fact that in one case the wave front traverses many bedding planes, while in the other case it traverses very few or none, may be largely responsible for the ratios obtained by the above-mentioned authors.

DERIVATIONS OF FORMULAS

In order to compare several computing methods on the basis of the horizontal displacements and depths which they produce for various reflection and stepout times, some type of configuration for the iso-velocity layers and a definite velocity versus depth gradient must be assumed. Since the case when the iso-velocity layers are horizontal (assumption A_2-1) is the easiest one to analyze and is the one most frequently postulated in practice, this is the one we shall assume. Furthermore, in accordance with the conclusions reached by Mott-Smith[11] in his discussion of what type of simple vertical velocity gradient gives the best overall fit to typical empirical velocity curves, we shall assume the instantaneous velocity, v, is a linear function of the vertical time, τ, that is,

$$v = v_o + a\tau, \tag{7}$$

where v_o is the initial velocity and a is a constant. This is equivalent to a parabolic function of depth, z, namely

$$v = (v_o^2 + 2az)^{1/2}. \tag{8}$$

The corresponding expressions for the average velocity are

$$\bar{v} = v_o + \tfrac{1}{2}a\tau = \tfrac{1}{2}(v_o + (v_o^2 + 2az)^{1/2}). \tag{9}$$

On the basis of the assumptions that the iso-velocity layers are horizontal and that the media are isotropic, the so-called curved-path method is the one that has physical meaning. Hence, this method will be taken as a norm to use as a basis of comparison for the other methods discussed, and the evaluation of the horizontal displacements and depths produced by this method for given times and stepout times will be undertaken first.

Curved-Path Method.—In an early paper, Slotnick[12] derived the integral formulas for the horizontal displacement, x, and travel time, t, corresponding to a given depth, z, of a seismic wave being propagated through isotropic media with horizontal iso-velocity layers, assuming the velocity to be an integrable function of depth. Using these formulas and assuming the velocity function in equation (8), Houston[13] derived the parametric equations for the cycloidal curved-path. It will be more convenient for our purposes, however, to derive the expressions for

[11] M. Mott-Smith, "On Seismic Paths and Velocity-Time Relations," *Geophysics*, IV (January, 1939), 8–23.

[12] M. M. Slotnick, "On Seismic Computations, I," *Geophysics*, I (January, 1936), 9–22.

[13] Charles E. Houston, "Seismic Paths, Assuming a Parabolic Increase of Velocity with Depth," *Geophysics*, IV (October, 1939), 242–246.

the horizontal displacement and the depth in terms of the parameter, t. This is most easily accomplished by first of all deriving the integral formulas for x and z in terms of t, which is done in a manner analogous to that described by Slotnick. These relations are:

$$x = \int_o^t pv^2(t)dt, \tag{10}$$

$$z = \int_o^t v(t)\left[\{1 - p^2v^2(t)\}^{1/2}\right]dt, \tag{11}$$

where

$$p = (\sin \alpha_o)/v_o = (\sin \alpha)/v, \tag{12}$$

α_o is the starting angle of the wave, v_o the initial velocity as before, α the angle between the vertical and the wave path at any point (equivalent to the angle of dip of the reflecting horizon at the reflection point for normal incidence) and v is the instantaneous velocity corresponding to any path time, t.

We shall also make use of the following integral formula for the path time in terms of the vertical time, τ:

$$t = \int_o^\tau pv^2(\tau)/[1 - p^2v^2(\tau)]^{1/2}d\tau. \tag{13}$$

Substituting the velocity function of equation (7) in equation (13), integrating and solving for v, one obtains

$$v = (1/p) \sin (apt + \alpha_o). \tag{14}$$

From equation (12), one can also write

$$v = (1/p) \sin \alpha. \tag{15}$$

Hence, equating equations (14) and (15),

$$\alpha = apt + \alpha_o. \tag{16}$$

Substituting equation (14) in equation (10), integrating and using equation (16), we have

$$x = (1/2p)[t - (1/2ap)(\sin 2\alpha - \sin 2\alpha_o)]. \tag{17}$$

Similarly, the substitution of equation (14) in equation (11), integration and reduction by means of equation (16) gives

$$z = (1/4ap^2)(\cos 2\alpha_o - \cos 2\alpha). \tag{18}$$

Now assume that we have two seismic paths defined by equations (17) and (18) which are normal to a straight reflecting horizon at the points of reflection. The submergent and emergent paths will then be coincident, and the angle α between the vertical and the tangent to the paths at the two points of reflection will

be the same and equal to the angle of dip of the reflecting horizon. The starting angles (call them α_o and α'_o) will be distinct. Furthermore, for simplicity, let the distance between the two paths at the datum be 1,000 feet.

Then, if x, z denote the horizontal displacement and depth of the first reflection point and x', z' the corresponding quantities for the second, it is evident that

$$\tan \alpha = \Delta z/(1 - \Delta x), \tag{19}$$

where

$$\Delta z = z - z',$$
$$\Delta x = x - x',$$

all distances being expressed in thousands of feet.

The following trial-and-error method can now be used to obtain the desired plot of x and z versus t for various Δt's and for fixed values of a and v_o. First of all, using equations (16), (17) and (18), plots are made of α, x and z versus α_o for various t's. Then, values for t and $\Delta t = t - t'$ are assumed, t being the single path time for the first path and t' that for the second. This fixes t'. Next, a value for the starting angle, α_o, is assumed and the corresponding value of α read from the first plot mentioned above. After the value for the second starting angle, α'_o, corresponding to t' is read from the same plot, the values of x, x' and z, z' corresponding to α_o, α'_o and t, t', respectively, are obtained from the other two plots mentioned above. From these results, the values of Δx, Δz and α can be calculated using equation (19). If this computed value of α is not the same as the assumed one, the process is repeated. Alignment charts may be used to speed up the work.

Straight-Path Method.—This method was mentioned earlier under assumption A_3 (see equation (2)), and is characterized by the fact that the path is assumed to be a straight line. If one assumes two such paths originating from shotpoints 1,000 feet apart and normal to a straight reflecting horizon, the average velocity in this case (see equation (9)) is given by

$$\bar{v}(t) = v_o + \tfrac{1}{2}at \cos \alpha, \tag{20}$$

since $\tau = t \cos \alpha$. Again letting t, t' denote the two path times, it is evident that $\sin \alpha$ is equal to the difference in length between the two paths, that is,

$$\sin \alpha = t\bar{v}(t) - t'\bar{v}(t'),$$

or, using equation (20),

$$\sin \alpha = \Delta t(v_o + \tfrac{1}{2}a\sigma \cos \alpha), \tag{21}$$

where $\Delta t = t - t'$ as before and $\sigma = t + t'$.

The identity of equations (2) and (21) for $s = 1$ is easily recognized when one notes that the average velocity over any interval between depths corresponding to vertical times τ_1, τ_2 is given by

$$\bar{v} = v_i = \frac{1}{\tau_2 - \tau_1}\int_{\tau_1}^{\tau_2} v(\tau)d\tau = v_0 + \tfrac{1}{2}a(\tau_1 + \tau_2), \tag{22}$$

using equation (7). Hence, if one puts $\tau_1 = t \cos \alpha$ and $\tau_2 = t' \cos \alpha$, it is seen that the coefficient of Δt in equation (21) is the average interval velocity.

Eliminating cos α from equation (21) gives for sin α

$$\sin \alpha = \frac{4v_0\Delta t + a\Delta t\sigma(4(1 - v_0^2\Delta t^2) + a^2\Delta t^2\sigma^2)^{1/2}}{4 + a^2\Delta t^2\sigma^2}. \tag{23}$$

Also, we have for the depth, z, of the first reflection point,

$$z = \bar{v}\tau,$$

or, using equation (20) and $\tau = t \cos \alpha$,

$$z = t \cos \alpha(v_0 + \tfrac{1}{2}at \cos \alpha); \tag{24}$$

and for the horizontal displacement,

$$x = z \tan \alpha,$$

or, substituting in equation (24),

$$x = t \sin \alpha(v_0 + \tfrac{1}{2}at \cos \alpha). \tag{25}$$

Hence, in order to obtain values of x and z corresponding to various t's and Δt's, one calculates the value of α for a given t and Δt (and hence a given t') from equation (23) and substitutes it and t in equations (24) and (25).

Modified Wave-Ray Method.—This method, which was described in the literature by Stulken,[14] is characterized by the fact that the average velocity over the reflection path is used to determine the angle of dip. (See equation (3) under assumption A_3.) The method is defined by the equations:

$$x = \bar{v}t \sin \alpha, \tag{26}$$

$$z = \bar{v}t \cos \alpha, \tag{27}$$

$$\sin \alpha = \bar{v}\Delta t, \tag{28}$$

again assuming a distance between shotpoints of 1,000 feet. It is a straight-path method and yet, as mentioned earlier, because of the fact that the average velocity over the two paths is assumed to be the same, that is an iso-velocity configuration of the type of Figure 1-*C* is assumed, displacements are smaller than those obtained by the straight-path method described above. In fact, as will be illustrated later, results obtained by this method are in very close agreement with curved-path values.

[14] E. J. Stulken, "Effects of Ray Curvature Upon Seismic Interpretations," *Geophysics*, X (October, 1945), 472–486.

Since the average velocity in this case is still given by equation (20), equation (28) becomes

$$\sin \alpha = \Delta t(v_o + \tfrac{1}{2}at \cos \alpha). \tag{29}$$

A comparison of equations (21) and (29) then shows that the expression for $\sin \alpha$ in terms of t and Δt is easily obtained by replacing σ by t in equation (23). The result is:

$$\sin \alpha = \frac{4v_o\Delta t + at\Delta t(4(1 - v_o^2\Delta t^2) + a^2t^2\Delta t^2)^{1/2}}{4 + a^2t^2\Delta t^2}. \tag{30}$$

The values of x and z for various t's and Δt's can be found by computing the values of α and $\bar{v}$ from equations (30) and (20), respectively, and substituting in equations (26) and (27).

Depth-Displacement Method.—Finally, consider the method mentioned in the introduction under assumption A_5, in which the paths are again assumed to be straight but the time-depth curve is applied to path times rather than to vertical times. The equations which define the method are the same as those for the straight-path method, except that the average velocity, which in this case is applied to t rather than to τ, is now given by

$$\bar{v} = v_o + \tfrac{1}{2}at. \tag{31}$$

Hence,

$$\sin \alpha = \Delta t(v_o + \tfrac{1}{2}a\sigma), \tag{32}$$

$$x = t(v_o + \tfrac{1}{2}at) \sin \alpha, \tag{33}$$

$$z = t(v_o + \tfrac{1}{2}at) \cos \alpha. \tag{34}$$

ILLUSTRATIVE EXAMPLES

As a specific example showing the results obtained using the various formulas derived above, take the velocity function given by equation (7) when $v_o = 8{,}000$ ft/sec and $a = 2.74$.

Figure 2 shows how the values of x and z obtained by the curved-path and straight-path methods compare for two-way reflection times ($2t$) from 0 to 4 secs and for two-way stepout times ($2\Delta t = 2(t - t')$) from 0 to 0.2 secs. Horizontal displacements are considerably larger and depths smaller than curved-path values for stepout times greater than zero.

Figure 3 compares results obtained by the modified wave-ray method with curved-path values for the same velocity function. Note how close together the two sets of values are for times and stepout times of magnitudes usually encountered.

Figures 2 and 3 provide a comparison of the three methods on a point-by-point basis, that is, they constitute an analysis "in the small." However, in order

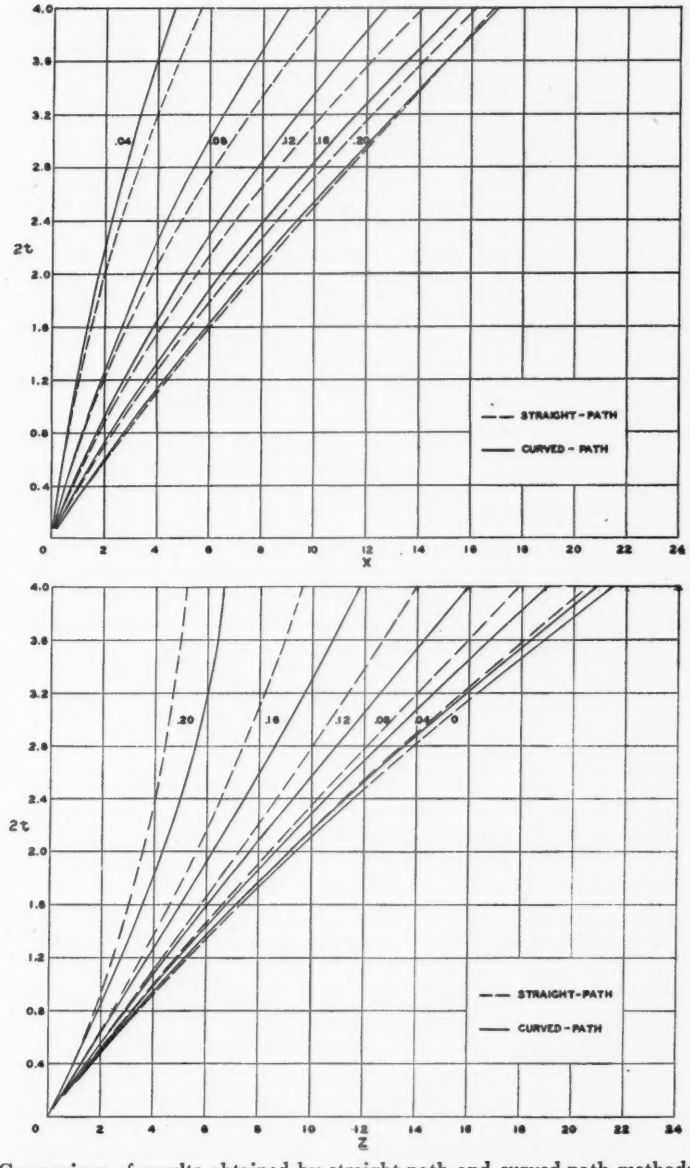


FIG. 2. Comparison of results obtained by straight-path and curved-path methods for various reflection times, $2t$, and stepout times, $2\Delta t$; x represents horizontal displacement and z depth of the reflection point.

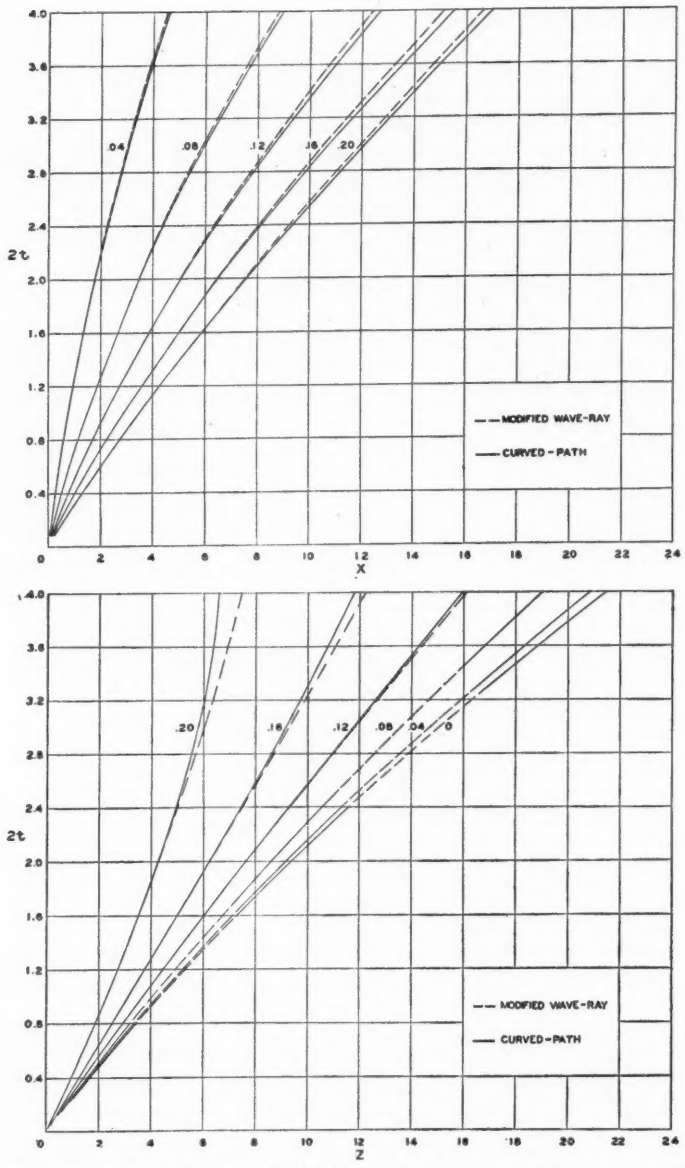
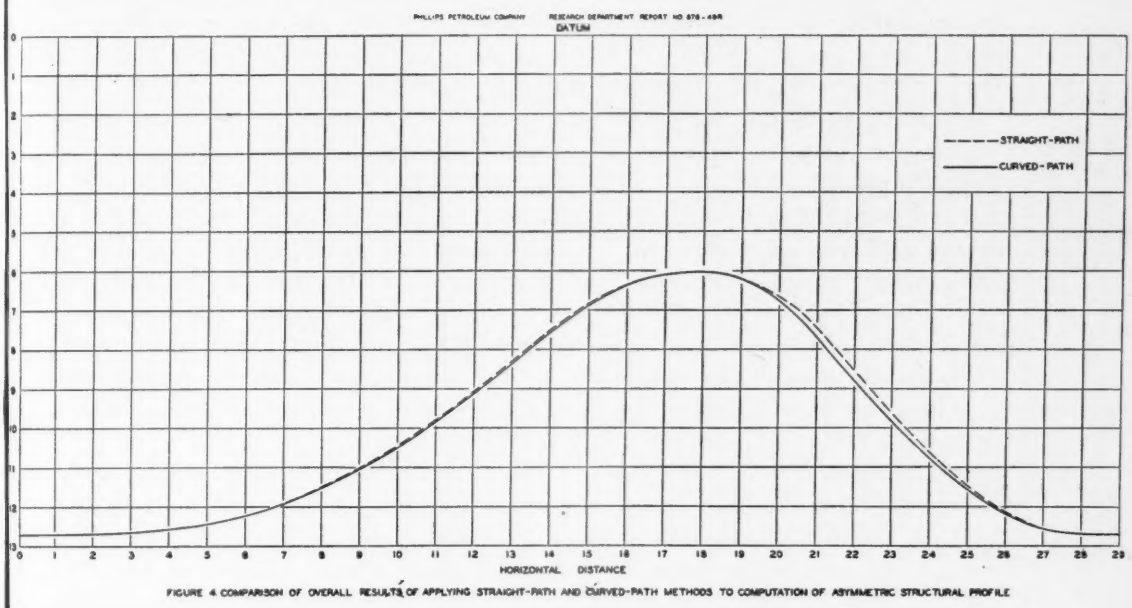


FIG. 3. Comparison of results obtained by modified wave-ray and curved-path methods for various reflection times, $2t$, and stepout times, $2\Delta t$; x represents horizontal displacement and z depth of the reflection point.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DATUM
STRAIGHT-PATH
CURVED-PATH
HORIZONTAL DISTANCE
FIGURE 4 COMPARISON OF OVERALL RESULTS OF APPLYING STRAIGHT-PATH AND CURVED-PATH METHODS TO COMPUTATION OF ASYMMETRIC STRUCTURAL PROFILE

FIG. 4. Comparison of over-all results of applying straight-path and curved-path methods to computation of asymmetric structural profile.

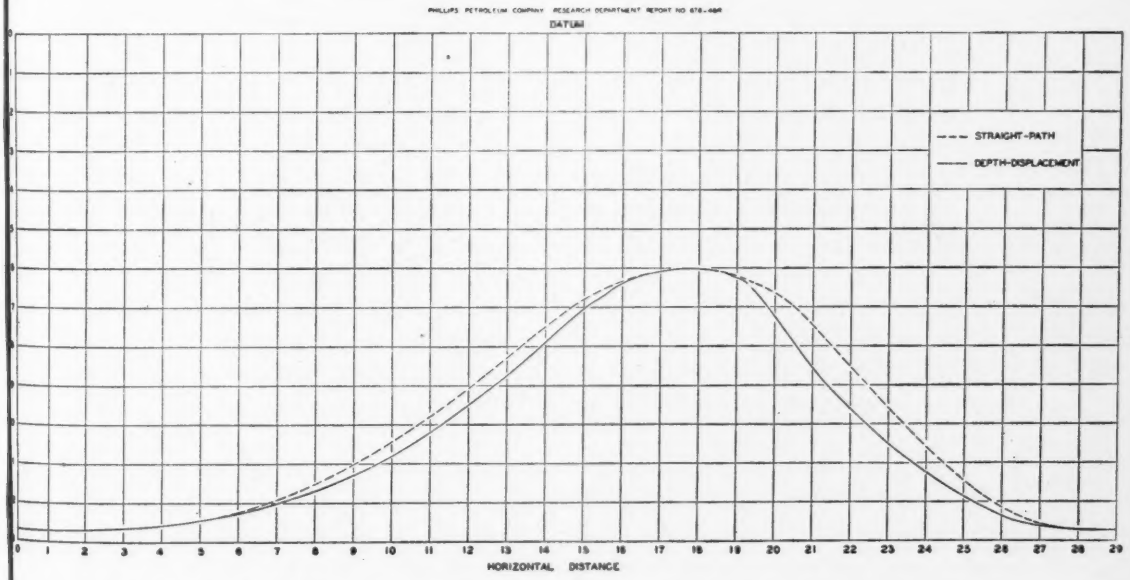

FIG. 5. Comparison of over-all results of applying straight-path and depth-displacement methods to computation of asymmetric structural profile.

to completely evaluate a given method, it is also necessary to show the results of using the method "in the large," that is, to determine the overall effect of applying it to the computation of the profile of a complete structure.

In order to do this, a hypothetical profile of an asymmetric structure was drawn, and shotpoints at 1,000-foot intervals along a datum were assumed. It was then postulated that this profile was the result of applying the curved-path method, using the same velocity function as above, to a unique set of t's and Δt's corresponding to the shotpoints. By trial-and-error methods, using a plot of Δt versus α for various t's and cross-plots from Figure 2 of Δt versus x and z for various t's superimposed on each other, a set of thirty-eight pairs of values of t and Δt which produce the assumed profile was found. Two-way times thus found range from 1.35 to 2.60 secs and two-way stepout times from 0 to 0.146 secs. Flanks of the structure were purposely assumed rather steep in order to bring out the differences between the various methods in sharper contrast.

Using this same set of t's and Δt's, the corresponding structural profiles obtained by means of the straight-path and depth-displacement methods were plotted. Figure 4 shows how the results obtained by the straight-path and curved-path methods compare, and Figure 5 shows a comparison between the straight-path and depth-displacement methods. No structural plot was made using the modified wave-ray method because of the fact that the profile obtained would be almost identical with the curved-path result.

It is interesting to note (Fig. 4) that, at least for the structure and velocity function chosen, the straight-path method, which is characterized by extremely large horizontal displacements, produces a structural profile which is fairly well in agreement with, but somewhat broader than that obtained by the curved-path method. This is due to the fact that, even though each reflection point is displaced considerably farther than the corresponding curved-path point, the depth is less by an amount which is enough merely to move the point up the structure.

On the other hand, horizontal displacements obtained by the depth-displacement method were so great that, at one point on the right flank of the structure (see the dotted portion of the curve between horizontal distances of 19 and 20, Fig. 5), the points piled up three deep. In comparing horizontal displacements obtained in calculating the structural profile with corresponding curved-path values, depth-displacement values of x were greater than curved-path results by values ranging up to 1,400 feet on the left flank and up to 2,000 feet on the right flank.

Note that in order to generalize the formulas derived above to the case when the two normal paths are at any distance, s, apart at the datum, one has merely to replace the denominator in the right member of equation (19) by $(s-\Delta x)$ and to substitute $\Delta t/s$ for Δt in equations (21), (23), (28), (29), (30) and (32). Then the various labels ranging from 0 to 0.20 on the curves of Figures 2 and 3 can be interpreted as values of the ratio $\Delta t/s$.

SEA-BOTTOM SLOPE DETERMINATION FROM WATER SOUND ARRIVALS*

W. B. AGOCS†

ABSTRACT

Previously[1] it was shown how the time break could be determined on deep-sea seismic records from the water sound arrivals. An extension of this problem has been made for the more general case of a sloping sea bottom. The depth of shot below the surface of the sea, shot-detector distance and the direction and magnitude of the sea-bottom slope may be determined by successive approximations. This is done, using the ratio of the difference in time of arrival of the direct water wave and the first reflection from the surface of the sea to the difference in time of the second and first reflection, and the ratio of the difference in time of arrival of the second and first reflections to the difference in time of arrival of the third and second reflections from the surface of the sea. The converse of the method could be used to determine sea-bottom slopes in hydrographic surveys.

INTRODUCTION

A method of determining the time break and shot-to-detector distance for a horizontal sea bottom was given previously.[2] The solution for the general problem of a sloping sea bottom is to be presented in this paper. The direct water sound arrival and the multiple reflections, or only the multiple reflections, may be utilized in making the determination of the shot-detector distance and the direction of slope.

It was already[3] shown that the velocity of sound in sea water varies zonally with depth, exhibiting four or five distinct velocity layers. For simplicity, the first layer is a zone of constant velocity, the second layer shows a velocity decrement, the third layer is approximately a constant velocity layer, and the fourth indicates a velocity increase with depth. The velocity increment in the zones is extremely small, and the radius of curvature of the ray path is of the order of 25,000 meters for the first, and 106 kilometers for the second zone of linear variation of velocity.

THEORY

For the case of the sloping sea-bottom reflecting surface, the problem is not as simple as that for a flat-bottomed sea. However, the problem is more general, and it is to be expected that sloping bottoms will be more generally met with in practice than flat sea bottoms.

In the case of two parallel reflecting surfaces, or in the case of a flat sea bot-

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[1] W. B. Agocs, "A Method of Determining the Time Break on Deep Sea Records from Water Sound Arrivals," *Geophysics*, IX (April, 1944), 163.

[2] *Ibid.*

[3] *Ibid.*

tom, the reflecting images lie on a normal plane on which the disturbance lies in the normal containing the disturbance and the recorder. The distance from the final image point to the recorder is the path length of the reflected-wave ray.

In the case of sloping reflecting surfaces, whether the disturbance lies on one of the reflecting surfaces or at an intermediate point, the reflecting images will lie on a circle whose center is located at the intersection of the extension of the reflecting planes, and whose radius is equal to the distance from the intersection of the planes to the disturbing point. The circle of images lies in the perpendicular plane containing the disturbance and the recording unit.

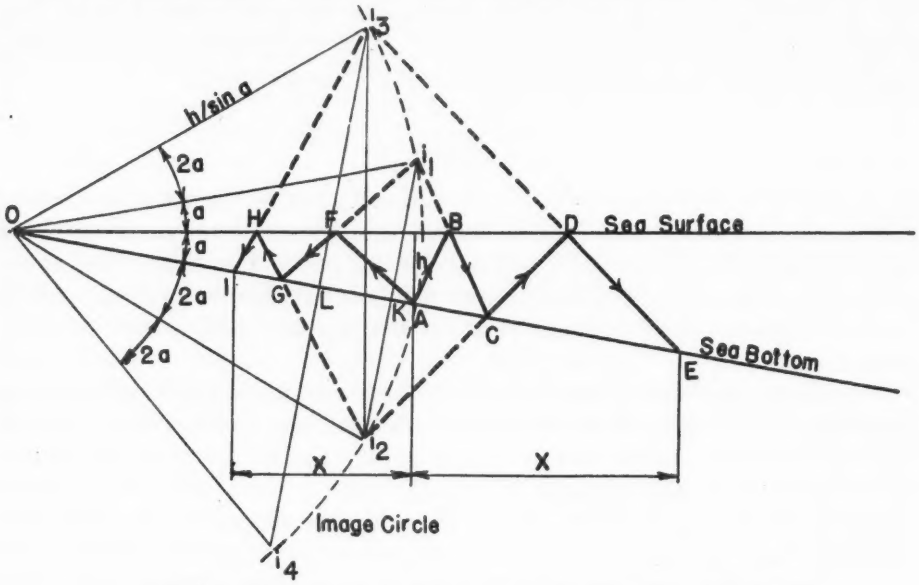

FIG. 1. Diagram showing image circle, location of reflection images, and second reflection path.

Referring to Figure 1, it may be observed that the first image lies on the image circle and is displaced an angle 2α from the disturbance, where α is the angle of slope. The image of the first reflecting image lies 2α below the disturbance, etc. Therefore, the separation of the images is 2α and the number of reflecting images that may be obtained will be limited by the number which is equal to $(\pi-\alpha)/\alpha$. As soon as the reflecting image falls behind the reflecting plane, no image for further reflection will result. Therefore, in the problem to be solved, the limiting slope that may be worked is 30°, since the third reflecting image will fall behind the reflecting surfaces for greater angles of dip.

Observations Down Dip from the Disturbance.—Referring to Figure 1, for the direct water sound arrival, it may be seen that the time of arrival of the disturbance, is

$$W - T_o = x/V \cos \alpha, \tag{1}$$

where W is the direct water-wave arrival time for the arbitrary instant of detonation, T_o is the correction in time from the arbitrary instant of detonation to the true instant of detonation, x is the horizontal separation of the disturbance and recording point, V is the velocity of sound at the depth of observation, and α is the angle of dip of the bottom.

Referring to Figure 1, it may be proven that the path length of the first reflection downslope is equal to a line drawn from i_1 to E. The reflection image i_1 lies on a circle whose radius is $h/\sin \alpha$, where h is the depth of the point of disturbance. Whence the right-angle triangle i_1EK may be used for the solution of path length of the wave using values of h, the depth, x, the separation, and functions of the angle of slope α in the solution. In the right-angle triangle i_1EK

$$i_1K = h \sin 2\alpha/\sin \alpha$$

and

$$KE = KA + AE = (x/\cos \alpha) + (h/\sin \alpha) - (h \cos 2\alpha/\sin \alpha)$$

and finally the path length

$$\begin{aligned} i_1E &= [(i_1K)^2 + (KE)^2]^{1/2} \\ &= \{(h \sin 2\alpha/\sin \alpha)^2 + [(x/\cos \alpha) + h(1 - \cos 2\alpha/\sin \alpha)]^2\}^{1/2}. \end{aligned}$$

The traveltime for the first reflection will be

$$\begin{aligned} (E_1 - T_o) = x\{&(h \sin 2\alpha/x \sin \alpha)^2 \\ &+ [(1/\cos \alpha) + h(1 - \cos 2\alpha)/x \sin \alpha]^2\}^{1/2}/\overline{V}, \end{aligned} \tag{2}$$

where $\overline{V}$ is the average velocity.

For the second reflection downslope, the path length of the reflected wave is $AB+BC+CD+DE$, as seen from Figure 1. The reflection images lie on the image circle. By geometry it may be shown that

$$i_3D = AB + BC + CD.$$

Whence, the right-angle triangle i_3EL, formed by the perpendicular bisector OE of the isosceles triangle i_3Ei_4, may be used in solving for the length of path travelled using the desired values h, x and functions of α in the solution. Hence

$$i_3L = h \sin 4\alpha/\sin \alpha$$

and

$$LE = LA + AE = (x/\cos \alpha) + (h/\sin \alpha)(1 - \cos 4\alpha).$$

Finally, the path length

$$AB + BC + CD + DE = [(i_3L)^2 + (LE)^2]^{1/2}$$

and the traveltime for the second reflection will be

$$E_2 - T_o = [(i_3L)^2 + (LE)^2]^{1/2}/\overline{V}. \qquad (3)$$

From the foregoing, it may be seen that the general time equation for the nth permitted reflection will be

$$E_n - T_o = x\{(h \sin 2n\alpha/x \sin \alpha)^2 + [(1/\cos \alpha) + h(1 - \cos 2n\alpha)/\sin \alpha]^2\}^{1/2}/\overline{V} \qquad (4)$$

where n is an integer, the number of the reflection.

The quantities W, E_1, E_2 and E_3 are known, and from equations (1), (2), (3) and (4), the problem of shooting down dip could be solved uniquely if V and $\overline{V}$ were both equal and constant. There would be four independent consistent simultaneous equations to solve for the four unknowns T_o, x, h and α. However V and $\overline{V}$ vary with h, but this may be accounted for in the solution of the equations since they vary within finite and small limits.

Eliminating T_o in equations (1), (2), (3) and (4) and taking the ratios of remaining equations will eliminate $\overline{V}$ from one set of the equations and the ratio of the velocities $\overline{V}/V$ may be made equal to a constant ρ. Hence the equations are reduced to

$$E_1 - W/E_2 - E_1 = \frac{\{(A \sin 2\alpha)^2 + [B + A(1 - \cos 2\alpha)]^2\}^{1/2} - \rho/\cos \alpha}{\{(A \sin 4\alpha)^2 + [B + A(1 - \cos 4\alpha)]^2\}^{1/2} - \{(A \sin 2\alpha)^2 + [B + A(1 - \cos 2\alpha)]^2\}^{1/2}}; \qquad (5)$$

$$E_2 - E_1/E_3 - E_2 = \frac{\{(A \sin 4\alpha)^2 + [B + A(1 - \cos 4\alpha)]^2\}^{1/2} - \{(A \sin 2\alpha)^2 + [B + A(1 - \cos 2\alpha)]^2\}^{1/2}}{\{(A \sin 6\alpha)^2 + [B + A(1 - \cos 6\alpha)]^2\}^{1/2} - \{(A \sin 4\alpha)^2 + [B + A(1 - \cos 4\alpha)]^2\}^{1/2}}, \qquad (6)$$

where $A = h/x \sin \alpha$ and $B = 1/\cos \alpha$.

Observations Up Dip from the Disturbance.—While the problem in shooting up dip from the disturbance is similar to that for shooting down dip, nevertheless it has its own peculiarities. While shooting down dip, the recording point is located outside the reflection-image circle, but in shooting up dip, the recording point is within the image circle. Hence, certain relations in the equations change, and it permits a unique solution.

Referring to Figure 1, the path length for the first reflection to record point I is equal to the line drawn from i_1 to I. The right-angle triangle i_1IK may be used for the solution of the path length of the wave using values of h, x and functions of the slope angle α.

$$i_1K = h \sin 2\alpha/\sin \alpha,$$

and

$$KI = h \cos 2\alpha/\sin \alpha - [(h/\sin \alpha) - x/\cos \alpha];$$

whence

$$i_1I = [(i_1K)^2 + (KI)^2]^{1/2}$$
$$= \{(h \sin 2\alpha/\sin \alpha)^2 + [(x/\cos \alpha) + h(\cos 2\alpha - 1)/\sin \alpha)]^2\}^{1/2},$$

or the time of the first reflection for shooting up dip is

$$E_1 - T_o = \{(h \sin 2\alpha/x \sin \alpha)^2 + [(1/\cos \alpha) + h(\cos 2\alpha - 1)/x \sin \alpha]^2\}^{1/2}/\overline{V}. \quad (7)$$

For the second reflection up dip from the disturbance at A (Fig. 1), the path length is $AF+FG+GH+HI$. It can be shown that

$$i_3H = AF + FG + GH,$$

and the right-angle triangle i_3IL formed by the bisector IE of the isosceles triangle i_3Ii_4 may be used to solve for the second reflection path length in terms of h, x and functions of α.

$$i_3L = h \sin 4\alpha/\sin \alpha$$

and

$$LI = h \cos 4\alpha/\sin \alpha - [(h/\sin \alpha) - x/\cos \alpha],$$

whence the path length is

$$i_3H + HI = AF + FG + GH + HI = [(i_3L)^2 + (LI)^2]^{1/2},$$

and the time for the second reflection shooting up dip is

$$E_2 - T_o = x\{(h \sin 4\alpha/x \sin \alpha)^2 + [(1/\cos \alpha) + h(\cos 4\alpha - 1)/x \sin \alpha]^2\}^{1/2}/\overline{V}. \quad (8)$$

From equations (7) and (8) it may be seen that the general equation for the nth reflection shooting up dip is

$$E_n - T_o = x\{(h \sin 2n\alpha/x \sin \alpha)^2 + [(1/\cos \alpha) + h(\cos 2n\alpha - 1)/x \sin \alpha]^2\}^{1/2}/\overline{V}. \quad (9)$$

Eliminating T_o in equations (1), (7), (8) and (9) and taking the ratios of the remaining equations yields the following:

$$E_1 - W/E_2 - E_1 = \frac{\{(A \sin 2\alpha)^2 + [B + A(\cos 2\alpha - 1)]^2\}^{1/2} - \rho/\cos \alpha}{\{(\overline{A} \sin 4\alpha)^2 + [\overline{B} + \overline{A}(\cos 4\alpha - 1)]^2\}^{1/2} - \{(A \sin 2\alpha)^2 + [B + A(\cos 2\alpha - 1)]^2\}^{1/2}}; \quad (10)$$

$$E_2 - E_1/E_3 - E_2 = \frac{\{(A \sin 4\alpha)^2 + [B + A(\cos 4\alpha - 1)]^2\}^{1/2} - \{(A \sin 2\alpha)^2 + [B + A(\cos 2\alpha - 1)]^2\}^{1/2}}{\{(\overline{A} \sin 6\alpha)^2 + [\overline{B} + \overline{A}(\cos 6\alpha - 1)]^2\}^{1/2} - \{(\overline{A} \sin 4\alpha)^2 + [\overline{B} + \overline{A}(\cos 4\alpha - 1)]^2\}^{1/2}}, \quad (11)$$

where $A = h/x \sin \alpha$ and $B = 1/\cos \alpha$.

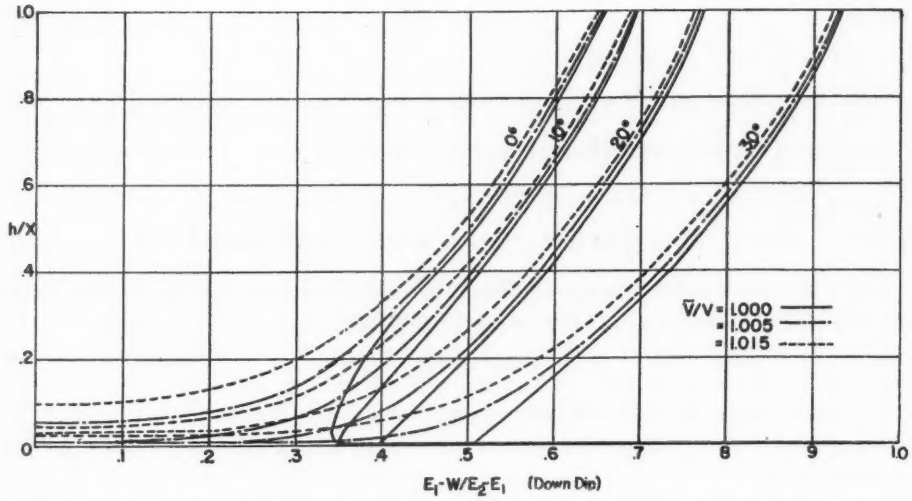

FIG. 2. Depth-lateral distance ratio relation to time-difference ratio for different slope angles.

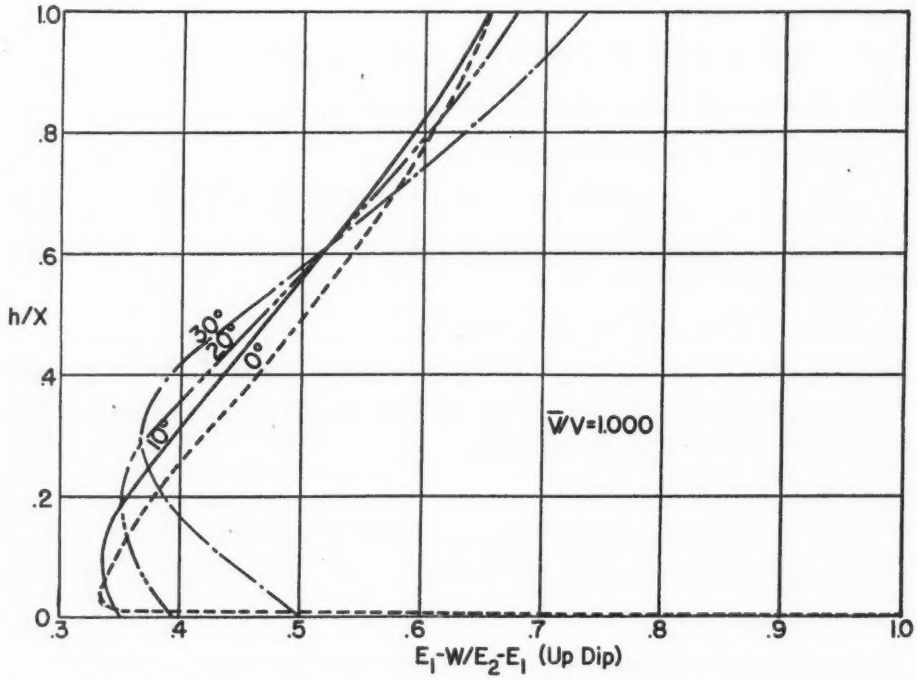

FIG. 3. Depth-lateral distance relation to time-difference ratio for up-dip shooting.

Solution of Equations for Shooting Up or Down Dip from a Disturbance.—The solution of the problem for determining the depth h, the separation x, and the slope α and its direction, and finally the instant of onset of the detonation can be solved by means of equations (1), (2), (3), (4), (7), (8) and (9). However, it may be seen that the solution of the equations would be extremely difficult and laborious. Hence, as in the case of a flat sea bottom, a graphic solution and successive approximations have been applied. Families of curves have been plotted from equations (5) and (10) for various values of slope angle α and progressively greater values of the ratio h/x for the ratio of E_1-W/E_2-E_1. These curves are shown on Figure 2 for the case of shooting down dip and on Figures 3, 4 and 5 for shooting up dip from the center of disturbance. The reason that this latter is drawn on three sets of curves is for ease of showing the curves on the scale used.

Families of curves have also been plotted for equations (6) and (11) for various values of slope angle α and for progressively greater values of the ratio h/x to the ratio E_2-E_1/E_3-E_2. These curves are shown in Figure 6.

Finally a family of curves has been plotted to facilitate the final calculations of the quantity

$$\{(A \sin 4\alpha)^2 + [B + A(1 - \cos 4\alpha)]^2\}^{1/2} - \{(A \sin 2\alpha)^2 + [B + A(1 - \cos 2\alpha)]^2\}^{1/2},$$

where $A = h/x \sin \alpha$ and $B = 1/\cos \alpha$ for down-dip shooting and of the same quantity, except for reversal of the values of the last term $(1-\cos n\alpha)$, for up-dip shooting. These values have been plotted against progressively greater values of the ratio h/x in Figure 7. A study of the curves for the shooting down dip shows that they are smooth and regular, and for the increasing values of angle show a regular distribution. On the other hand, in the up-dip shooting, it is found that the curves, while regular and smooth, tend to cross, and the deviation of one curve from the other for various values of the angle is small. The reason for this is attributed to the fact that the function of the ratios of these trigonometric functions is almost equal. However, there is sufficient differentiation between the various curves so that a unique solution and a determination may be made as to the direction and value of the dip.

The method of determining the value of the ratio h/x for a particular set of data is as follows:

A) The ratio of the times E_1-W/E_2-E_1 and of E_2-E_1/E_3-E_2 is determined from the recordings.

B) A first determination of the ratio h/x is found from the curves of Figures 2, 3, 4 or 5 and Figure 6, for the ratio of velocities equal to unity; the value of h/x is that value for which the angle of slope and its direction agrees simultaneously for the curves from Figures 2 or 3, 4, 5, and Figure 6.

C) When the direction and the degree of dip have been determined for the

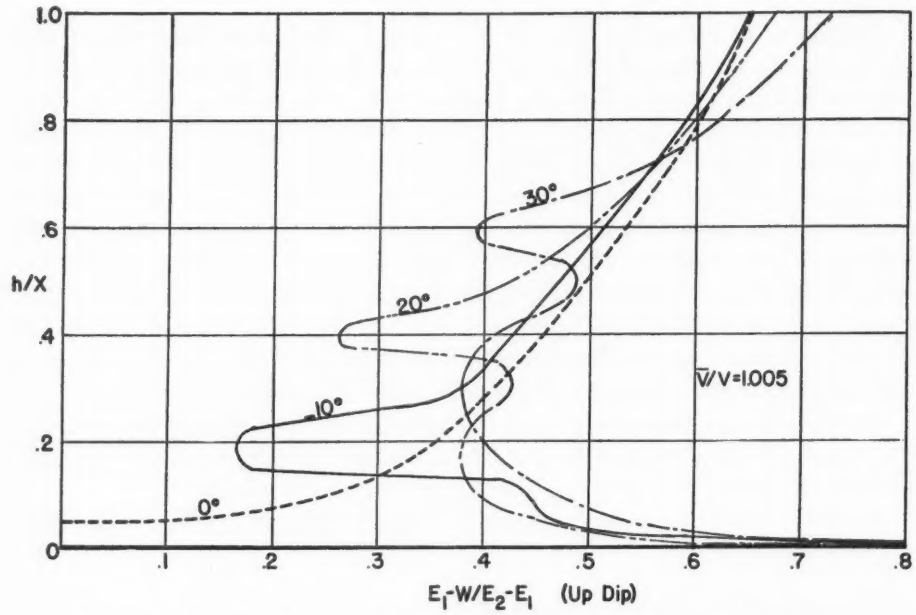

FIG. 4. Depth-lateral distance relation to time-difference ratio for up-dip shooting.

proper ratio h/x, a solution may be made for x by using the family of curves of Figure 7 for this value of h/x, and using the difference of equations (2) and (3) or equations (7) and (8).

D) Once the approximate value of x has been determined, the value of h can be calculated, since the ratio of h/x was found in step *B*. When the first approxi-

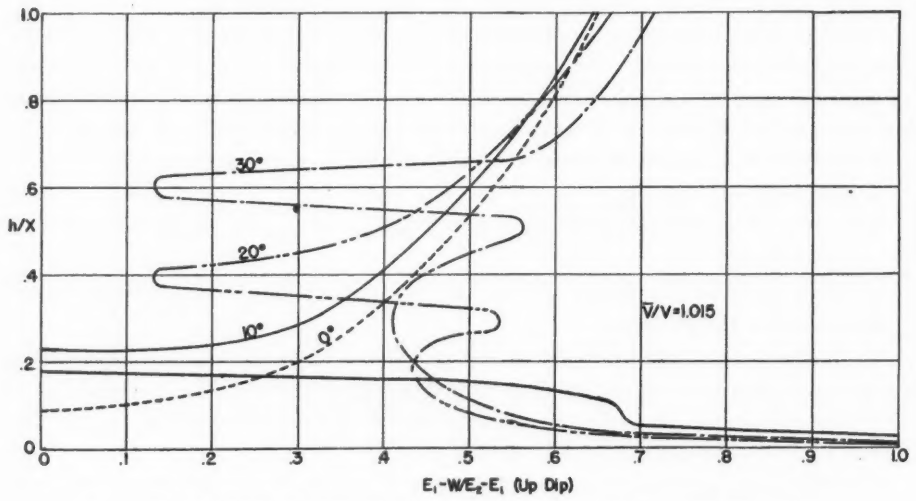

FIG. 5. Depth-lateral distance relation to time-difference ratio for up-dip shooting.

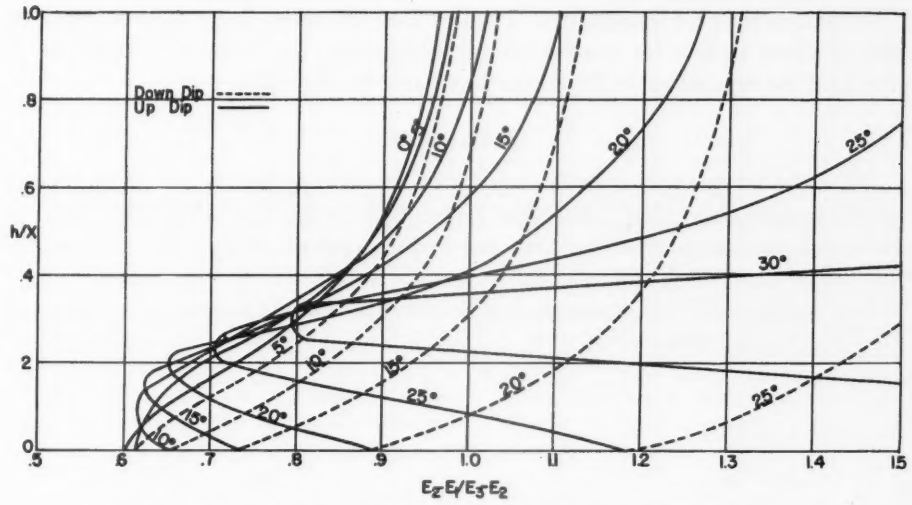

FIG. 6. Depth-lateral distance relation to ratio of differences of reflection times.

mation of h has been determined, an approximate value of the ratio of $\overline{V}/V$ can be found from the velocity—depth curve,[4] and a closer approximation obtained for the value of h/x since a more nearly correct value of the ratio $\overline{V}/V$ can be determined. Finally, substituting the values of x, V and α in equation (1), the instant

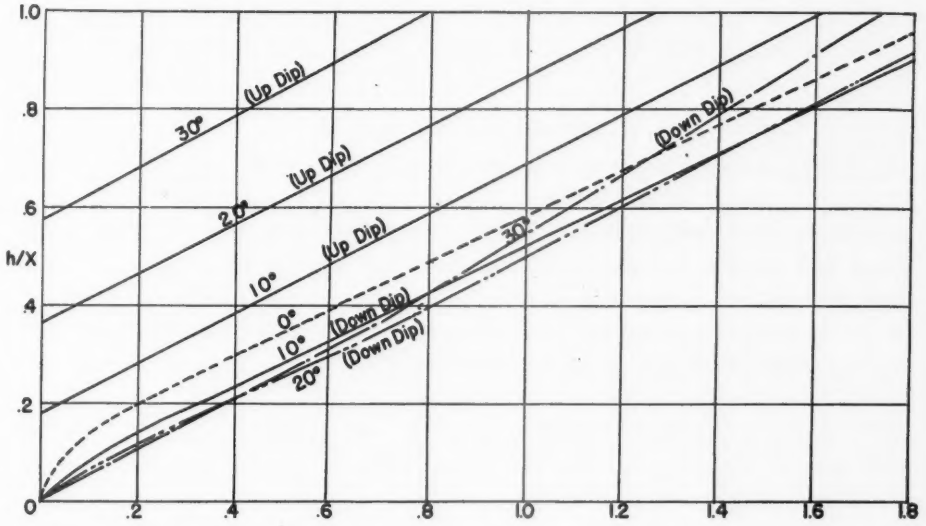

FIG. 7. Relation of ratio of depth-lateral distance to difference between first and second reflection.

[4] *Ibid.*

of detonation may be determined. Two, and at the most three, approximations yield accurate results for the instant of detonation, the angle and direction of slope, and the separation of the disturbance and the recording point.

CONCLUSION

From the foregoing it may be seen that the method offers a tool to be used in oceanic seismic surveying. The paper presents a method for obtaining the time break, and the necessary survey data for deep-sea seismic operations which would be recorded along with the sub-bottom seismic data.

The method may be modified, slightly, for use in sonic sounding from the sea surface, using multiple "echoes" in the manner shown above for slope and depth determinations.

DERIVATION OF MAGNETIC AND GRAVITATIONAL QUANTITIES BY SURFACE INTEGRATION*

D. C. SKEELS† AND R. J. WATSON‡

ABSTRACT

In an earlier paper by one of the authors, it was pointed out that if the vertical component of a gravitational or magnetic field is known over a horizontal plane surface of sufficient extent, all other components and derivatives of the field can theoretically be calculated by surface integration of the vertical component. In this paper, examples are given to show that within certain limits such calculations are not only theoretically possible but practically so. Examples are given of the calculations of curvatures from observed gradients and of horizontal magnetic intensity from observed vertical intensity, and the calculated values are compared with those obtained by observation. Examples are also given, based on artificial data, of the calculation of plumb-line deflections from gravity and of the calculation of magnetic anomalies at a given elevation above the earth from data obtained at the surface. The purpose of these calculations is to demonstrate the nonindependence of the various derivatives of gravitational and magnetic potential.

INTRODUCTION

It was pointed out in a previous paper[1] that the various derivatives of the gravitational or magnetic potential are not independent of one another; and that, in theory at least, all of the derivatives and the potential itself, can be calculated if the values of gravity (in the case of magnetics, the vertical component) are known in sufficient detail over a large enough area.

Since the appearance of the paper mentioned, the authors have encountered a number of geophysicists who are inclined to question either the theoretical or the practical validity of the above statement. Therefore, it seems worth-while to give some examples in which such calculations were carried out, on both actual and synthetic data.

METHODS OF CALCULATION

Let us assume for the moment that we have an infinite horizontal plane and that we know the values of gravity at all points on this plane. Let (x, y, z) be the coordinates of a point above this plane (which will be on the plane when $z=o$) and let (x', y', o) be the coordinates of a point on the plane. Let $U(x, y, z)$ be the value of the gravitational potential at the point (x, y, z) above the plane or on it, and $g(x', y', o)=(\partial U/\partial z)(x', y', o)$ be the value of gravity at the point (x', y', o) on the plane. Then, by the corollary of Green's theorem, it is shown that

$$U(x, y, z) = \frac{1}{2\pi}\int_s \frac{1}{R}\left(\frac{\partial U}{\partial z}\right)(x', y', o)ds, \qquad (1)$$

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[1] D. C. Skeels, "Ambiguity in Gravity Interpretation," *Geophysics*, XII (January, 1947), 43–56.

where R is the distance $\sqrt{(x-x')^2+(y-y')^2+(z-z')^2}$ (see Fig. 1) and the integration is to be carried out over the entire surface of the plane.

This theorem defines the potential at any point either on the surface (when $z=o$) or above it, in terms of a surface integral of the values of the derivative of potential normal to the surface and the variable $1/R$. Since the product inside the integral can be evaluated for any point on the surface, the integration can be readily carried out, either by numerical or by graphical means.

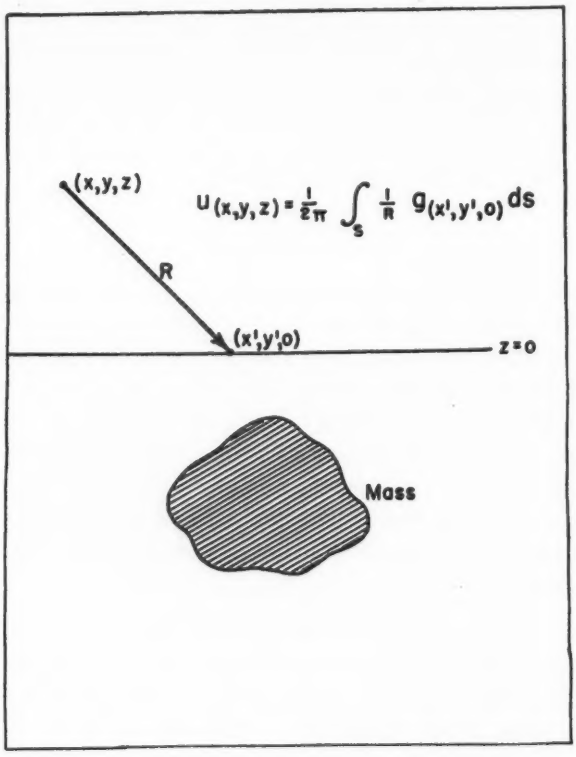

FIG. 1. Potential as a surface integral.

There is a rather convenient physical interpretation of this theorem which may be helpful to many readers who find it easier to think in terms of physical principles than of mathematical symbols. If we imagine a thin sheet of material spread over our infinite plane surface, which is the surface over which we have observations of gravity, and that the mass per unit area of this sheet varies from place to place, then the potential at the point (x, y, z) due to a small area of the sheet ds, whose coordinates are (x', y', o), and whose mass per unit area is $\rho(x', y', o)$ will be $\Delta U(x, y, z) = (K/R)\rho(x', y', o)ds$, and the potential due to the entire sheet will be

$$U = \int_s (K/R)\rho(x', y', o)ds, \tag{2}$$

where K is the gravitational constant.

Comparing this expression with equation (1), we see that they will be identical if we make

$$\rho(x', y', o) = \frac{1}{2\pi K} g(x', y', o) = \frac{1}{2\pi K}\left(\frac{\partial U}{\partial z}\right)(x', y', o). \tag{3}$$

In other words, whatever the unknown mass distribution below the surface is, we can replace it by a theoretical surface distribution in which the mass per unit area at any point is proportional to the value of gravity at that point. This surface distribution will have the same potential at all points on the surface, or above it, as the subsurface distribution of mass. Since the potential due to the actual and theoretical distribution is the same at all points of space above the plane, it follows that the derivatives of the potential for the two distributions must be identical.

We can, therefore, replace the unknown subsurface distribution by a known theoretical surface distribution. But for any known mass distribution, it is a relatively simple matter to calculate the value of the potential or any of its derivatives at any point. If we wish to calculate curvature values, for example, when the values of gravity are known, we simply calculate the curvatures for the equivalent surface distribution of mass. Or, if we wish to calculate the horizontal magnetic intensity, we replace the unknown subsurface distribution of magnetic poles by a surface distribution in which the pole density is proportional to the observed vertical intensity, and calculate the horizontal components of attraction of this theoretical distribution of poles.

We are usually more interested in the derivatives of the potential than in the potential itself. These derivatives could be obtained by calculating the potential at a large number of points, plotting various curves of the potential, and obtaining the slopes of these curves graphically. It is much simpler, however, to differentiate equation (1) to obtain a new expression for the desired quantity in terms of surface integrals of gravity. For example, suppose we wished to determine from a gravity map what value gravity would have at a point some distance above the surface of observation. Then we differentiate both sides of equation (1) with respect to z to obtain

$$g(x, y, z) = \left(\frac{\partial U}{\partial z}\right)(x, y, z) = \frac{1}{2\pi}\int_s \frac{\partial}{\partial z}(1/R)g(x', y', o)ds. \tag{4}$$

It should be noted that $g(x', y', o)$, the value of gravity at a point on the surface $z=o$, is not a variable for the purpose of this differentiation, since it is not a function of the unprimed coordinates. The distance R is a function of both

primed and unprimed coordinates, and therefore a variable for purposes of the differentiation.

If we wish to calculate the horizontal magnetic intensity on the plane $z=o$ when the vertical intensity is known, we substitute V (magnetic potential) for U, and differentiate both sides with respect to x and y to get

$$\left(\frac{\partial V}{\partial x}\right)(x, y, o) = \frac{1}{2\pi}\int_s \frac{\partial}{\partial x}\left(\frac{1}{R}\right)\left(\frac{\partial V}{\partial z}\right)(x', y', o)ds \tag{5}$$

for the x component, and

$$\left(\frac{\partial V}{\partial y}\right)(x, y, o) = \frac{1}{2\pi}\int_s \frac{\partial}{\partial y}\left(\frac{1}{R}\right)\left(\frac{\partial V}{\partial z}\right)(x', y', o)ds \tag{6}$$

for the y component.

In the examples which follow, we have evaluated the surface integrals by means of specially constructed templates or graticules, which divide the surface into areas of unequal size but such that the value of the integral divided by the value of gravity shall be the same for all the elements of area, the value of gravity being assumed to be constant within a given compartment. It is only necessary to lay this template over the map, write down the value of gravity in each compartment, add the values, and multiply by a constant, to obtain the derived value for the point at the center of the chart. The chart is then moved to another point on the map, and the derived value calculated for that point, and so on. Figure 10 shows such a chart for calculating $\partial U/\partial x$ from $\partial U/\partial z$, when $z=o$. The procedure is very similar to that often used for calculating isostatic corrections for pendulum stations.

In theory, the integration is to be carried out over the entire surface of an infinite sheet, whereas in practice our data are limited to a finite area. It can easily be demonstrated, however, that the term $1/R$ (or its derivative), which occurs in the intergrand, falls off so rapidly with distance that for any desired accuracy, there is always some finite distance beyond which the contribution to the integral is so small that it can be neglected.

This explanation also takes care of another objection, that whereas the theorem refers to observations on a horizontal plane, gravity observations are reduced to a spheroidal datum. In most cases the area over which the integration is carried out is so small that the departure of the spheroid from a plane surface introduces only a negligible error.

There may be a more serious objection in the case of observations made in very rough terrain. In the case of magnetic data, there is usually no reduction to a datum. Even in the case of gravity observations, the reduction usually employed is not complete, in that the calculated gravity values, even when corrected for terrain, are not quite the same as those which would have been observed at the datum level had the material above datum been removed. The reason for this is

that the vertical gradients due to the anomalous masses are neglected. In most cases, however, it can be shown that this is not a large source of error.

EXAMPLES

Calculation of Horizontal Magnetic Intensity from Vertical Intensity Data.—Our first example is illustrated in Figure 2. The lower part of the figure shows the cross section of a hypothetical structure, which is assumed to have a differential susceptibility of $\Delta K = 2{,}000 \times 10^{-6}$ cgs units and to be magnetized by induction in an inclined field of 0.5 gauss, as shown. It is assumed that the mass is two-dimensional, that is, that this is the cross section of a prism of infinite horizontal extent. We can easily calculate the vertical- and horizontal-intensity profiles which would be observed at the surface (the middle line of the figure) for such a mass, by using a two-dimensional magnetic graticule (identical with the graticule used for torsion-balance quantities). The solid profiles were calculated directly from the cross section of the mass in this manner. From the vertical profile so calculated, we then computed a second horizontal-intensity profile by surface integration, using the fundamental equation

$$\left(\frac{\partial V}{\partial x}\right)(x, y, o) = \frac{1}{2\pi}\int_s \frac{\partial}{\partial x}\left(\frac{1}{R}\right)\left(\frac{\partial V}{\partial z}\right)(x', y', o)ds, \tag{7}$$

which, for the two-dimensional case, reduces to the line integral

$$\left(\frac{\partial V}{\partial x}\right)(x, o, o) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} \frac{1}{x}\left(\frac{\partial V}{\partial z}\right)(x', y', o)ds. \tag{8}$$

The horizontal profile so calculated is shown by the broken line in Figure 2. It can be seen that it agrees fairly closely with the "observed" horizontal profile, although it does not coincide with it exactly. The difference may be due in part to errors in the original graticule calculations by which the "observed" profiles were obtained, errors in calculating the value of the line integral, which was also by graticule, and errors introduced by neglecting the contributions to the integral from beyond a certain finite distance.

Figure 3 shows another example calculated from hypothetical data, in which the third dimension had to be considered as well. The upper part of the figure shows the vertical-intensity contours for a dipping magnet, which lies in the vertical plane whose trace is $A-A'$ (where A' is north). These contours were calculated by formula and drawn as accurately as possible. The middle part of the figure shows a section along A–A' (south to north) in which are seen the assumed dipole, the profile along this section, the Δz profile calculated by formula, and the ΔH profile calculated by surface integration of the *contours* (for which a graticule similar to that of Figure 10 was used). In the lower part of the figure, the two ΔH curves are shown for the section B–B', which is oblique to the plane of symmetry. In both cases the curves calculated by surface integration can be seen to be very similar to those calculated directly from the formula.

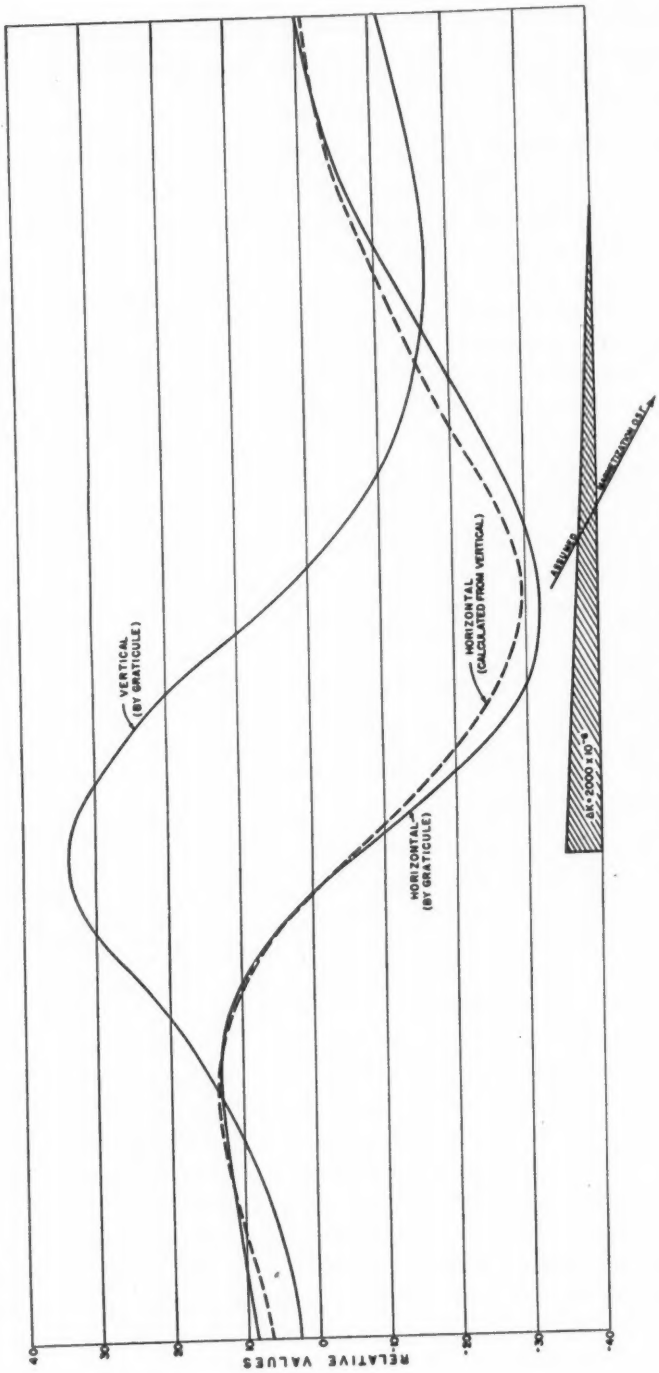

FIG. 2. Theoretical magnetic anomalies.

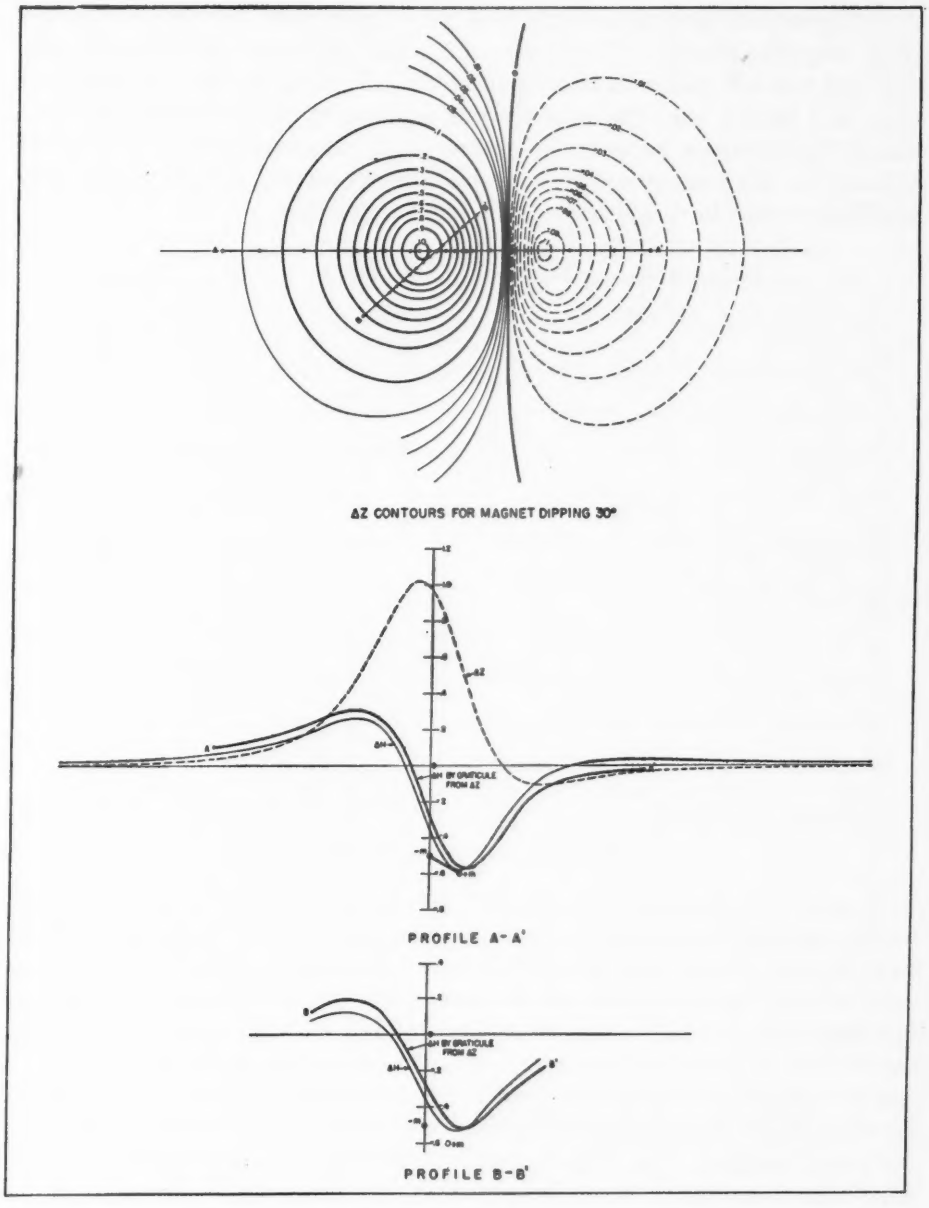

FIG. 3. Calculation of ΔH and ΔZ.

In Figure 4 we have an example from actual field data. The data are for the Kursk magnetic anomaly.[2] The observed ΔZ and ΔH curves are shown as solid lines, and the ΔH profile calculated from the ΔZ profile by line integration is shown as a broken line. The anomaly was assumed to be two-dimensional, and some of the difference between the observed and calculated ΔH curves may be attributed to this assumption. Since we are dealing now with actual data, some of the difference may be due to errors in the observed profiles.

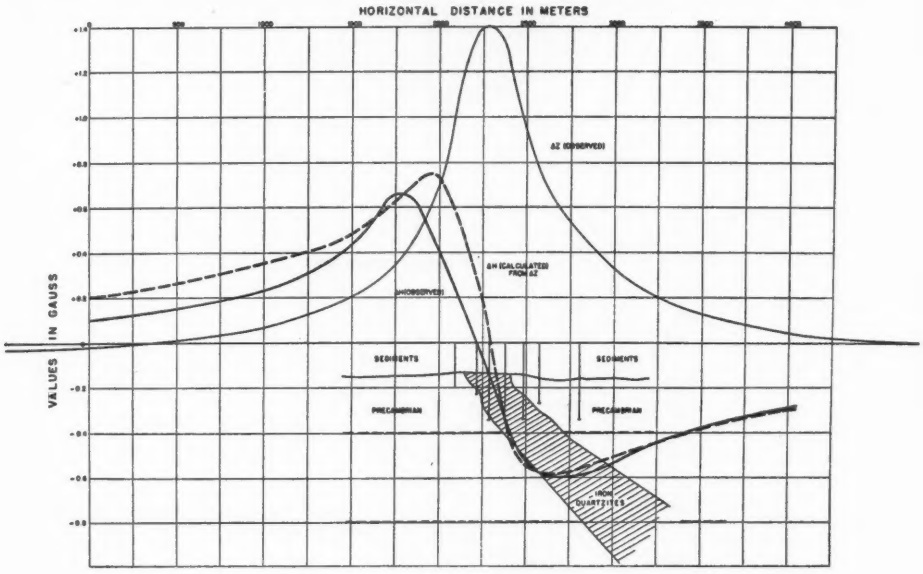

FIG. 4. Kursk magnetic anomaly.

Figure 5 is an example from a magnetic survey of an area in Ecuador, in which both vertical and horizontal components were observed. The profiles were drawn from the maps, across anomalies which were sufficiently elongated so that it was believed that the assumption of two-dimensional character would not introduce any large errors. It can be seen that there is fairly close agreement between observed and calculated ΔH-values except at the extremities of the profile, where it was necessary to extrapolate the profile in order to obtain values. The divergence between observed and calculated profiles may indicate that the extrapolation was not a very good one. This suggests that by trial and error, an extrapolation might have been found which would have given a better fit between the two ΔH profiles. That is, the addition of horizontal data to vertical data may be justified in cases where some parts of an area are inaccessible for observation, in helping to extrapolate the vertical data across such areas.

Calculation of Curvatures from Gradients.—The calculation of torsion-balance

[2] C. A. Heiland, *Geophysical Exploration* (New York: Prentice-Hall, Inc., 1940), 410.

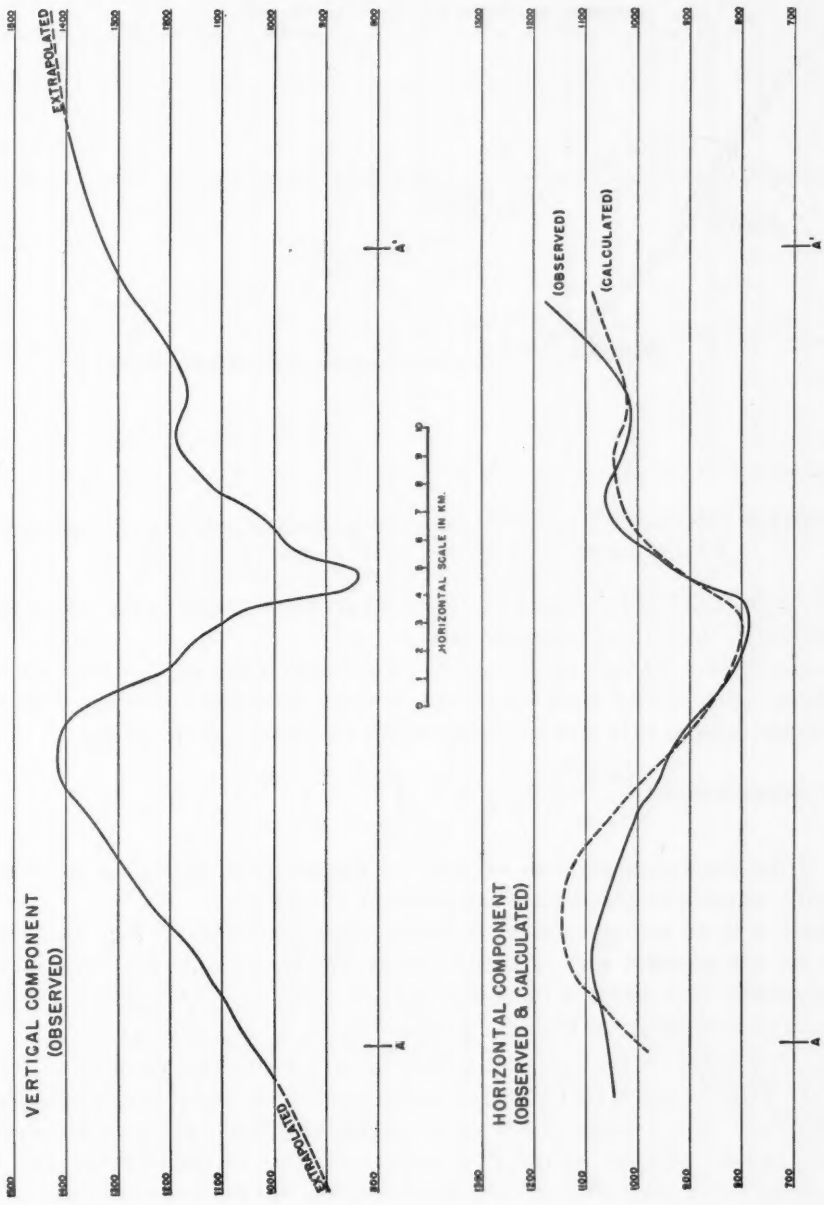

FIG. 5. Calculation of horizontal magnetic intensity from vertical data.

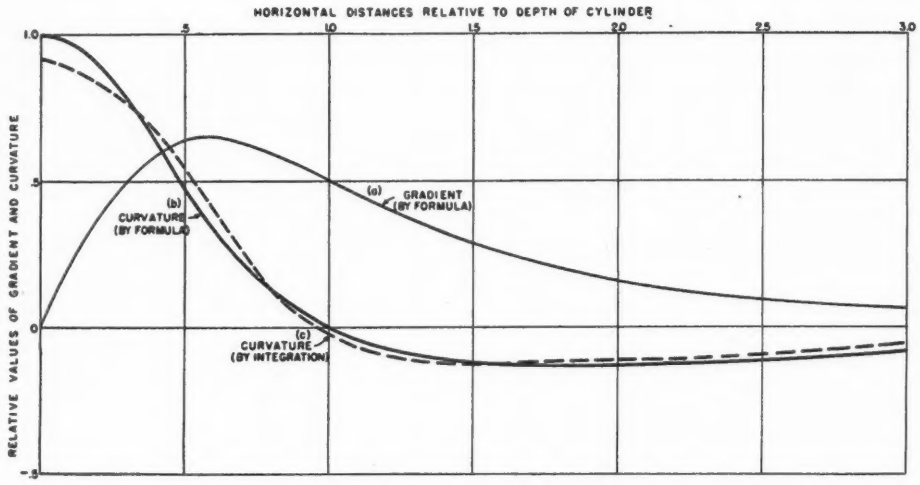

FIG. 6. Gradient and curvature of horizontal infinite cylinder. Gradient and curvature calculated by formula, and curvature derived from the gradient by integration.

curvatures from gradients in the two-dimensional case is similar to the calculation of horizontal from vertical magnetic data.

If we introduce the variable $W = \partial U/\partial x$, we have gradient $= \partial^2 U/\partial x \partial z = \partial W/\partial z$ and curvature $= \partial^2 U/\partial x^2 = \partial W/\partial x$. Since W is a harmonic function, Green's theorem also applies to it, and we can write, for the two-dimensional case

$$\text{curvature} = \left(\frac{\partial W}{\partial x}\right)(x, o, o) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} \frac{1}{x}\left(\frac{\partial W}{\partial z}\right)(x', o, o)dx, \qquad (9)$$

which is the same expression as we used for magnetics in the two-dimensional case, with curvature replacing ΔH and gradient replacing Δz.

Figure 6 is an example calculated from hypothetical data. The two solid curves are the gradient and curvatures calculated by formula for a horizontal infinite cylinder at a depth of 1.0 on the distance scale, and the dashed line is the curvature profile calculated from the gradient profile by line integration.

Figures 7 and 8 are examples calculated for actual data taken from the literature.[3,4] In Figure 8 the actual observed values are shown, and it can be seen that the curvature values especially deviate considerably from the smooth profile accepted as the "average" of the observed values. The calculated curvatures fit this average curve fairly well on the right-hand side, but deviate considerably on the left. Since we obtained much better agreement for the calculations involving

[3] W. F. P. MacLintock and J. Phemister, "The Case of the Torsion Balance in the Investigation of Geological Structure in Southwest Persia," *Geol. Survey of Great Britain, Summary of Progress* (1926), 177.

[4] A. H. Miller, "Torsion Balance Surveys of the Hull-Gloucester and Hazeldean Faults," *Can. Geol. Survey, Mem. 165* (1931), 202–203.

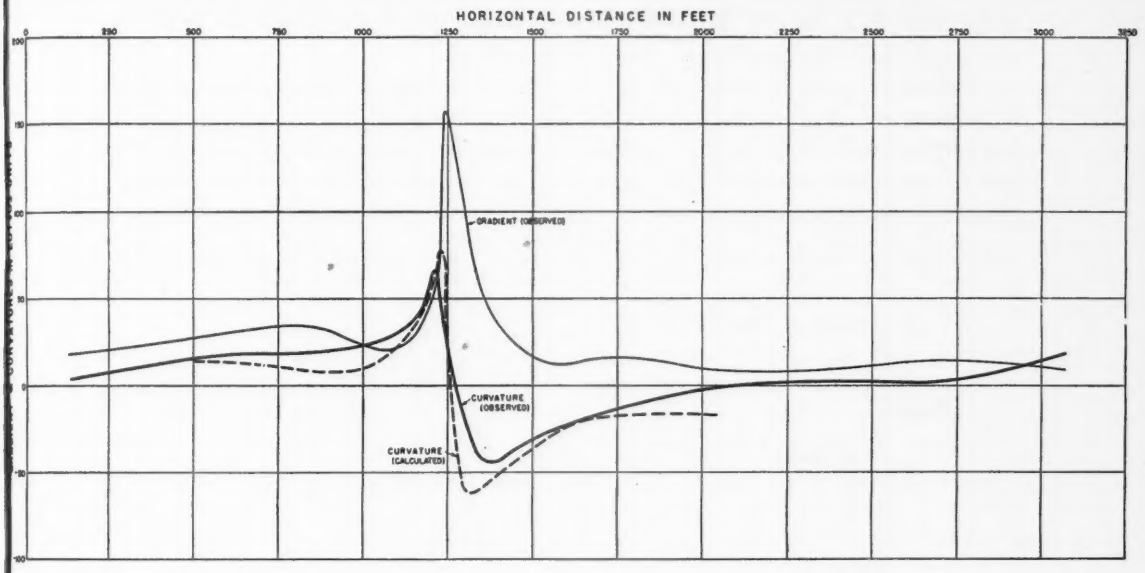

FIG. 7. Derivation of curvature from gradients: Hull-Gloucester fault.

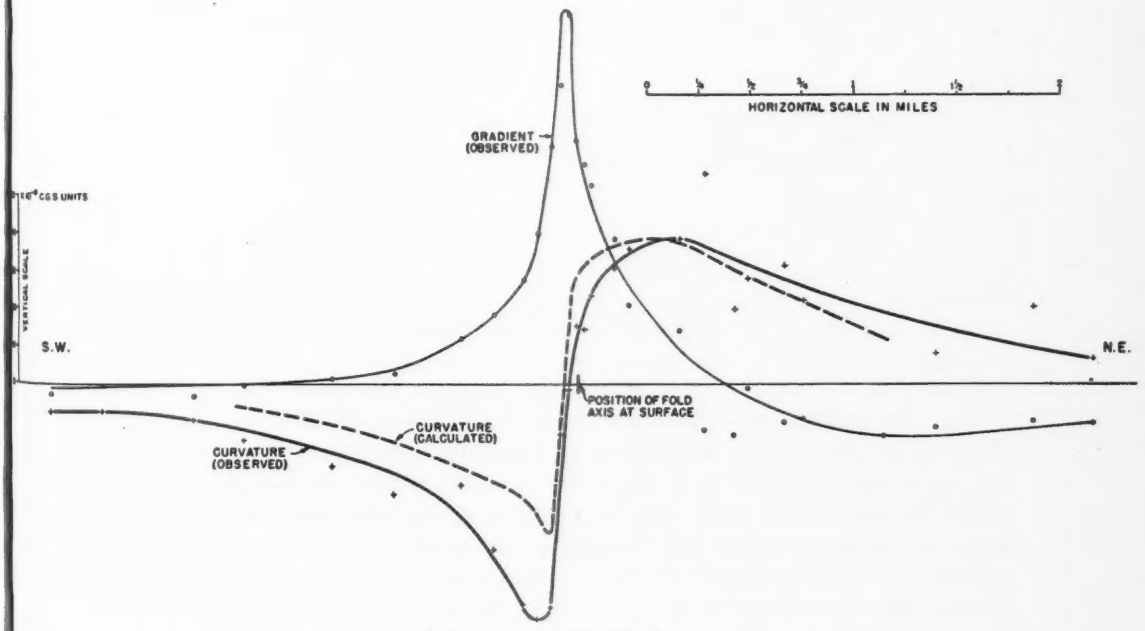

FIG. 8. Azwah traverse-Iran.

theoretical data, we feel justified in asserting that the discrepancies are probably due to errors in the data rather than in the method.

Deflections of the Vertical.—A localized excess of mass in the subsurface causes anomalies not only in gravity, but also in the direction of the plumb line; these are termed deflections of the vertical. A simplified case is illustrated in Figure 9. Let the horizontal line represent the surface of the earth, and let the circle represent the cross section of a spherical mass below the surface. At a given

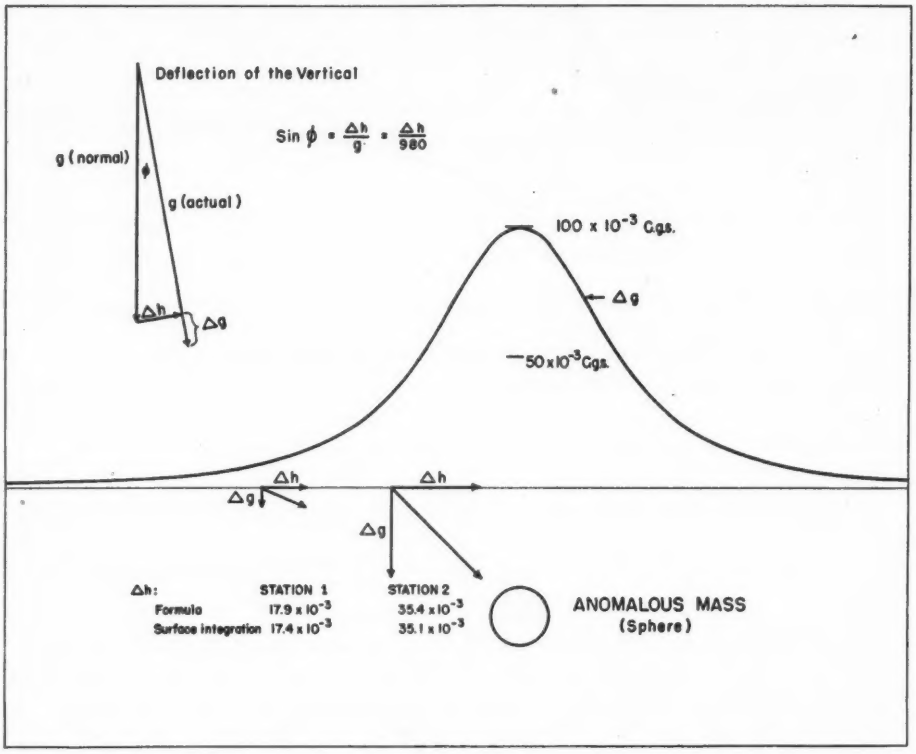

FIG. 9. Deflection of the vertical.

point on the surface, the attraction of the mass for the plumb bob is directed along a line joining the station and the center of the spherical mass. The total force on the plumb bob, which is what determines the direction of the plumb line, is the resultant of the anomalous force and the normal force of gravity. This causes the plumb line to be deflected slightly toward the anomalous mass, as shown in the upper figure. The anomalous force can be resolved into two components: one parallel to the plumb line, which we call Δg, or the vertical component, and one normal to the plumb line, which we call Δh, and which is, of course, the horizontal component of the anomalous force. If ϕ is the deflection angle, it can be seen from the figure that $\sin \phi = \Delta h/g$ where g is the normal force

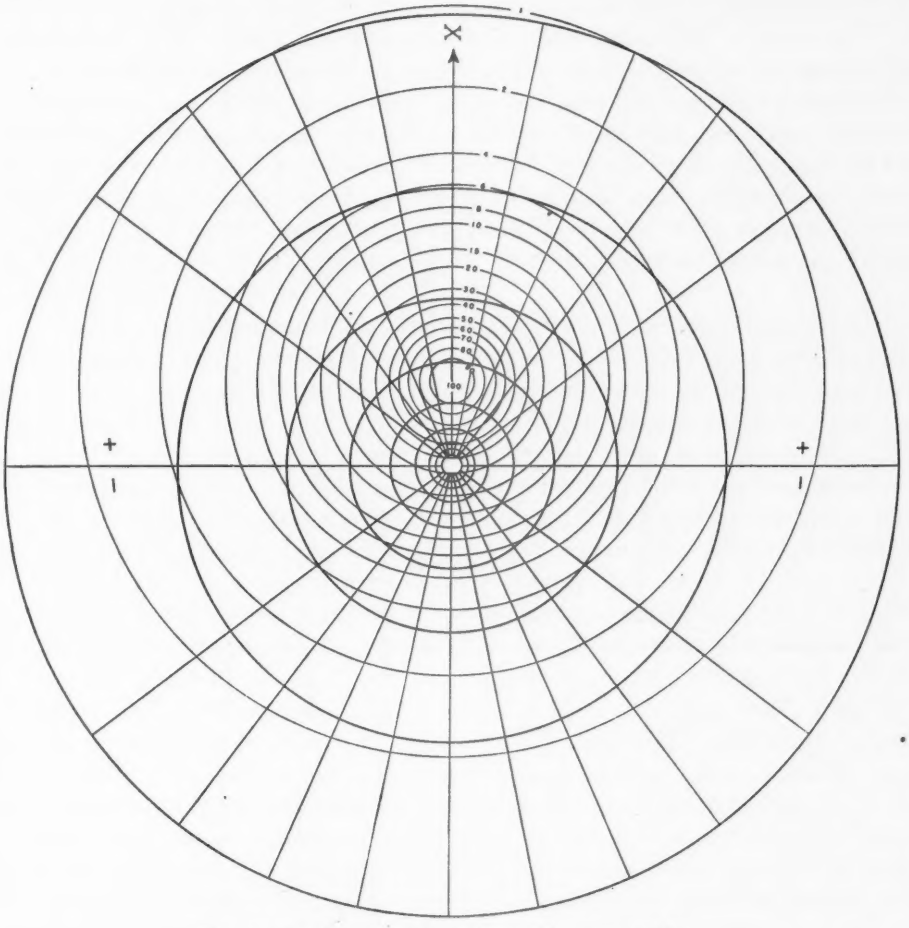

FIG. 10. Graticule for calculating $\partial U/\partial x$ from $\partial U/\partial z$.

of gravity. We introduce very little error if we substitute for g its approximate value of 980 gals, then $\sin \phi = \Delta h/980$.

If we know Δg over a sufficiently large area, we should be able to calculate the value of Δh, the anomalous horizontal component at any point, and hence determine the deflection of the vertical at that point. For a rigorous calculation we should take into consideration the curvature of the earth, but if the area covered by the anomaly is not too large, we can get a good approximation by assuming the observation surface to be an infinite horizontal plane.

The problem is similar to that of calculating horizontal from vertical magnetic intensity; our equation is

$$\Delta h = \frac{\partial U}{\partial x} = \frac{1}{2\pi}\int_s \frac{\partial}{\partial x}\left(\frac{1}{R}\right)\Delta g \, ds \qquad (10)$$

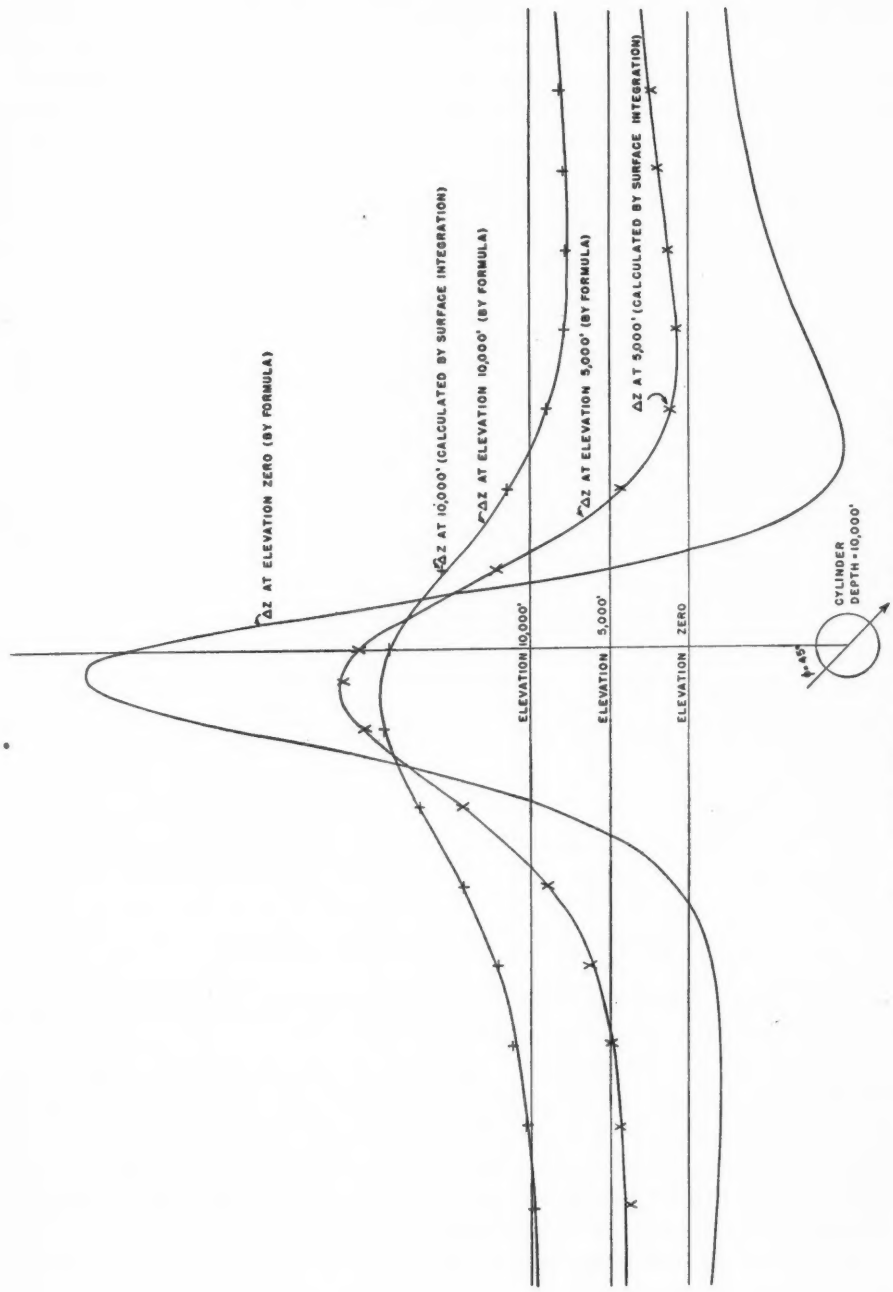
ΔZ AT ELEVATION ZERO (BY FORMULA)
ΔZ AT 10,000' (CALCULATED BY SURFACE INTEGRATION)
ΔZ AT ELEVATION 10,000' (BY FORMULA)
ΔZ AT ELEVATION 5,000' (BY FORMULA)
ΔZ AT 5,000' (CALCULATED BY SURFACE INTEGRATION)
ELEVATION 10,000'
ELEVATION 5,000'
ELEVATION ZERO
CYLINDER DEPTH = 10,000'
φ = 45°

FIG. 11. Calculation of magnetic field at different levels.

in which U refers to the potential of the anomalous mass only.

The integral was evaluated by means of the chart shown by the heavy lines in Figure 10. The lighter circles show the Δg contours calculated for the sphere of Figure 9. The chart is laid over the Δg contour map, with the center over the station at which the value of Δh is required. The graticule or chart divides the map into compartments such that the contribution of each compartment to the integral (except for the central circle) is proportional only to the average value of Δg in the compartment. The small central circle is treated separately, as will be described in the Appendix.

The horizontal component Δh was computed from the contours by means of the graticule at two stations, as shown in Figure 9. At the same two stations the value of Δh was also calculated by formula. At the first station, which is at a horizontal distance from the peak of the gravity maximum equal to twice the depth of the sphere, the value obtained by surface integration was 0.0174 gals and by the formula 0.0179 gals. At the second station, where the horizontal distance equals the depth, the value obtained by surface integration was 0.0351 and by formula 0.0354. The deflection of the vertical at station 2 would therefore be $\phi = 0.0354/980$ or 0.000036 radians, or 0.12 minutes.

Derivation of the Field at Points Above the Surface.—With the airborne magnetometer, it is now possible to make magnetic observations at various elevations above the surface of the earth, and some areas have actually been flown at several levels. The advantages to be gained from data at two or more levels are probably not as great as has been claimed. In the first place, our theory tells us that if there is no unique interpretation for the magnetic map at one level, the ambiguity will not be resolved by adding data from another level; that is, if two different magnetic distributions can be found which satisfy the field at one level, they will also satisfy the field at all higher levels. In the second place, if we know the field at one level, we should be able to calculate it at any higher level by use of equation (4) (substituting magnetic for gravitational quantities).

Figure 11 shows the results of such a calculation for the case of the vertical component of the magnetic field due to a horizontal cylinder of infinite length. Magnetic profiles were first calculated by the rigorous formula for three elevations, 0, 5,000, and 10,000 feet above the datum plane (or 10,000, 15,000, and 20,000 feet above the axis of the cylinder). The profile on the zero level or datum plane was then taken as the "observed" profile, and values at the other two levels were derived from it by line integration. These derived values are shown in Figure 11 by crosses. In all cases they fall either on or very close to the profile calculated by formula. This example was calculated on a much larger scale, and the integration was extended to a greater distance than in the former examples. This may account in part for the closer fit between derived and theoretical values in this example as compared to the others. Another reason is probably that when calculating effects at some distance above the surface of observations, the variable $1/R$ never approaches infinity, which it does for calculations in the same plane.

The calculations are, therefore, not so sensitive to small variations (which may be errors) in the part of the profile immediately adjacent to the point for which the calculation is being made.

Vertical intensity data were used in the example calculated above, whereas the airborne instruments in most widespread use measure total intensity. It can be demonstrated, however, that the same method of calculation can be applied to total intensity data, provided the anomalies are small enough that the direction of the total field remains essentially unchanged. The total intensity, which is measured in the direction of the normal field, and therefore inclined to the vertical, can, in fact, be shown to be the vertical gradient of a function P which satisfies Laplace's equation, so that equation (4) applies.

The purpose of this paper has been to demonstrate, by examples, that within limits and provided sufficient data are available, various derivatives of the potential can be calculated by surface integration and to indicate how such calculations may be carried out. We are not making any claims here for the practical value of such calculations. We have indicated one possible application in the extrapolation of data where observations are incomplete but where two kinds of data are available. There may be other applications. It seems to us, however, that the most important point is that since one quantity can be derived from another, they are not independent. The ambiguity inherent in one set of observations of a derivative of a potential is not resolved by adding observations of another derivative or of the same derivative at another level.

APPENDIX

Derivation of chart for calculating $\partial U/\partial x$ from $\partial U/\partial z$, for $z=o$ (Fig. 10).

Take θ such that

$$\sin\theta = \frac{x' - x}{r}, \qquad \cos\theta = \frac{y' - y}{r}.$$

Therefore

$$ds = rdrd\theta.$$

Then

$$\frac{\partial U}{\partial x} = \frac{1}{2\pi}\int_s \frac{\partial}{\partial z}\left(\frac{1}{r}\right)\frac{\partial U}{\partial z}\,ds$$

$$= \frac{1}{2\pi}\int_s \frac{x' - x}{r^3}\cdot\frac{\partial U}{\partial z}\,rdrd\theta$$

$$= \frac{1}{2\pi}\int_o^{\infty}\int_o^{2\pi} \frac{\partial U}{\partial z}\,\frac{\sin\theta}{r}\,drd\theta.$$

Now consider a small area of the surface, bounded by the circles of radii r_1 and r_2, and by the radii of angles θ_1 and θ_2. The contribution of this element to $\partial U/\partial x$ is

$$\Delta\left(\frac{\partial U}{\partial x}\right) = \frac{1}{2\pi}\int_{\theta_1}^{\theta_2}\int_{r_1}^{r_2}\frac{\partial U}{\partial z}\,\frac{\sin\theta}{r}\,dr d\theta.$$

If the element is sufficiently small, $g=\partial U/\partial z$ can be considered a constant and equal to its average value in the compartment, so we have

$$\Delta\left(\frac{\partial U}{\partial x}\right) = \frac{g}{2\pi}\left[(\cos\theta_1 - \cos\theta_2)(\log r_2 - \log r_1)\right].$$

Hence, if we divide the whole surface into a number of small cells, such that the quantity in the brackets has the same value for each cell, we have only to find the average value of Δg in each cell, add the values for all cells, and multiply by a factor, to get the value of the integral.

We encounter a difficulty when $r=o$, for $\log r$ becomes infinite. We can get around this as follows: About the origin we draw a small circle with radius r_1, small enough that we can assume the gradient of gravity to be constant within this circle. Let m be the rate of change of gravity in the x direction, and n the rate of change in the y direction; let g_o be the value of gravity in the center of the circle. Then at any point inside the circle

$$\begin{aligned} g &= g_o + mx + ny \\ &= g_o + mr\sin\theta + nr\cos\theta \end{aligned}$$

and for the whole circle

$$\begin{aligned} \Delta\left(\frac{\partial U}{\partial z}\right) &= \frac{1}{2\pi}\int_o^{r_1}\int_o^{2\pi}\left(g_o\frac{\sin\theta}{r} + m\sin^2\theta + n\sin\theta\cos\theta\right)dr d\theta \\ &= \frac{1}{2}mr_1. \end{aligned}$$

Therefore, for the whole surface

$$\frac{\partial U}{\partial x} = \frac{1}{2}mr_1 + \frac{1}{2\pi}\sum g_n(\cos\theta_n - \cos\theta_{n+1})(\log r_{n+1} - \log r_n).$$

Suppose we take the value of $(\cos\theta n - \cos\theta n+1)$ as 0.2 for each cell, and $(\log r_{n+1} - \log r_n)$ as 0.5, then the value of each cell is 0.1 $g/2\pi$. In the first quadrant, the values of θ and its cosine are:

θ	$\cos\theta$
0°	1.00
36°50′	0.80
53°10′	0.60
66°25′	0.40
78°30′	0.20
90°00′	0.00

The values of the radius and its logarithm are:

r	log r (natural)
1.0	0
1.65	0.50
2.72	1.00
4.48	1.50
7.39	2.00
12.2	2.50
20.2	3.00
33.2	3.50

The arrow on the graticule indicates the positive direction of x; if x is taken as north, for example, the graticule is oriented with the arrow pointing north. The line through the center, perpendicular to the arrow, divides the chart into positive and negative halves.

For $\partial U/\partial y$, the same chart is used by orienting with the arrow in the positive y direction.

CORRELATION OF GRAVITY OBSERVATIONS WITH THE GEOLOGY OF THE COAL CREEK SERPENTINE MASS, BLANCO AND GILLESPIE COUNTIES, TEXAS*

FREDERICK ROMBERG† AND VIRGIL E. BARNES‡

ABSTRACT

Gravitational observations were made of the pre-Cambrian Coal Creek serpentine mass in Blanco and Gillespie Counties, Texas, the geology of which had been mapped previously. The observed gravitational anomalies indicate roughly the depth of the serpentine mass below which it may possibly grade into its parent peridotitic rock. Probable correlation between the gravitational map and the other geologic features of the area is indicated.

INTRODUCTION

The investigation of the gravitational effects of a serpentine mass is one of several projects by the writers[1,2] in the application of gravitational observations to the prediction of the shape of rock masses in the basement. The Coal Creek serpentine mass is situated in central Texas, astride the Blanco-Gillespie County line a short distance south of the juncture of these counties with Llano County. The geology of the area, mapped by Barnes mostly in 1939 and 1940, is in part described by Barnes, Dawson, and Parkinson.[3] During 1942 and 1943 in connection with a detailed investigation of soapstone, some revisions were made of the mapping north of the serpentine mass.[4] Planetable-alidade traverses were made to obtain positions and elevations of the gravity stations, and with these data seven and one-half minute quadrangles have been compiled from which the generalized geologic map accompanying this paper was taken.

Observations were made with a portable gravity meter over the rough areas which include the serpentine mass and some adjacent territory. Along roads away from the serpentine mass, observations were made using a standard-sized gravity meter. Gravity observations and reduction of these observations were made by both writers; however, Romberg is responsible for the final gravity interpretations. Barnes is responsible for the geological observations and interpretations.

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[1] Frederick Romberg and V. E. Barnes, "Correlation of Gravity Observations with the Geology of the Smoothingiron Granite Mass, Llano County, Texas," *Geophysics*, IX (Jan., 1944), 79–93.

[2] V. E. Barnes and Frederick Romberg, "Gravity and Magnetic Observations on the Iron Mountain Magnetite Deposit, Llano County, Texas," *Geophysics*, VIII (Jan., 1943), 32–45.

[3] V. E. Barnes, R. F. Dawson, and G. A. Parkinson, "Building Stones of Central Texas," *Univ. Texas Pub. 4246* (1942), 90–91, 108–111, 113–114, Fig. 11.

[4] V. E. Barnes, "Soapstone and Serpentine in the Central Mineral Region of Texas," *Univ. Texas Pub. 4301* (1943), 47–80, Figs. 22–24.

At this point we wish to make it clear that the serpentine mass described in this paper is a part of the pre-Cambrian basement and is not related to the Cretaceous serpentine plugs of the Balcones fault zone. The conclusions in this paper cannot be applied to the Cretaceous serpentine plugs.

GEOLOGY

The Coal Creek serpentine mass takes its name from Coal Creek, a broad intermittent stream filled with granite wash, which crosses the western end of the serpentine outcrop. The mass is 3.7 miles long in an east-west direction and ranges from 0.3 to about 1.4 miles wide with important lobes at each end. The surface outcrop of the serpentine totals 2.54 square miles, of which 45 percent is in the attenuated 2.1 mile-long central part of the mass, 20 percent in the western end of the mass, and 35 percent in the eastern end. The widest part of the outcrop is at the eastern end of the serpentine mass.

The Coal Creek serpentine is derived from a basic igneous rock, and the abundant network structure seen in thin section indicates that the rock was originally mostly olivine. Another mineral, probably an amphibole, also has been replaced by serpentine. The presence of recognizable pseudomorphs shows that there has been little disturbance of the serpentine after its formation. The outcrop form and attitude of the serpentine suggest that it is essentially a thick sheet curved northward at each end, and such a sheet should extend, as a minimum, at least several miles in depth.

The attitude of the main body of the serpentine, as determined from observations along its border and from observations of inclusions and alignments within the serpentine, suggests that it dips about 45 degrees to the south in its western part, steepening eastward to about 60 degrees where the mass curves northward and changes its dip to southeastward. The attitude of the serpentine beyond this point was not determined.

The serpentine is bordered along the south and for the western half of its distance along the north by Big Branch gneiss[5,6] of quartz diorite composition. The rest of the distance along its northern side is bordered by Packsaddle schist, which here is chiefly amphibole and mica schist containing numerous soapstone lenses. Valley Spring gneiss outcrops in the southwestern part of the map area, as well as Town Mountain granite which outcrops also in the southeastern part of the map area. Paige[7] has defined the Packsaddle schist and Valley Spring gneiss and Stenzel,[8] the Town Mountain granite. Other outcropping types of rock such as diorite and hornblendite are common, but the masses are not of sufficient size to alter noticeably the gravity map. Paleozoic sediments mask the pre-Cambrian

[5] *Ibid.*, pp. 56–57.

[6] Barnes, Dawson, and Parkinson, *op. cit.*, Fig. 11.

[7] Sidney Paige, "Llano-Burnet, Texas, Folio of the Geologic Atlas of the United States," *U. S. Geol. Survey Folio 183* (1912), 3–4.

[8] H. B. Stenzel, "Pre-Cambrian Structural Conditions in the Llano Region," *Univ. Texas Bull. 3401* (1934), 75–79.

rocks both to the west and east. These areas stand high and are relatively inaccessible, limiting the area in which gravity observations can readily be obtained.

The Valley Spring gneiss and the Packsaddle schist are metasedimentary rocks, into which the Big Branch gneiss has been intruded. The formation of soapstone from calcareous rock in the Packsaddle schist apparently happened at this time and is not related to the later injection of peridotite from which the serpentine was formed. The essentially undeformed minerals of the serpentine and the presence of Packsaddle schist, soapstone, and Big Branch gneiss inclusions indicate that the peridotite emplacement postdates the period of metamorphism that accompanied the injection of the Big Branch gneiss. An aplite dike in the serpentine may be an offshoot of the Town Mountain granite, in which case the original emplacement of the serpentine would be earlier than that of the Town Mountain granite. The aplite, however, could possibly be interpreted as an inclusion, in which case the serpentine would be later.

The emplacement of the serpentine is definitely pre-Cambrian in age since it is overlapped by Cambrian sediments. The erosional surface upon which the Cambrian sandstone was deposited probably in no place was more than a few hundred feet above the present erosional surface. The Cambrian sediments were mostly stripped prior to the deposition of Cretaceous sediments, the base of which was only a few hundred feet above the present surface.

Some information on the density of the pre-Cambrian rocks follows:

	Density	*No. Determinations*
Serpentine	2.48	6 (Theoretical 2.55–2.58)
Big Branch gneiss	2.75	9
Packsaddle schist	2.95	8[9]
Valley Spring gneiss	2.64	25[9]
Town Mountain granite	2.62	7[9]

More detailed accounts of the geology are contained in the publications cited, and seven and one-half minute quadrangles of most of the area are being prepared showing more detail than does the map accompanying this paper.

Some generalizations on the time of formation of serpentine in relation to its emplacement are contained in geologic literature which do not seem to be supported by the Coal Creek serpentine mass. Hess[10] suggests that water may be picked up by peridotite to form serpentine from water-bearing geosynclinal sediments. The Coal Creek mass did not intrude geosynclinal sediments, not at least at the level now being observed. If geosynclinal sediments existed above this level, which is doubtful, their contained water would not have been available for serpentinization of this deeper portion of the mass. As pointed out by Bowen[11] it is unlikely that the water for serpentinization could be contained in the peridotite,

[9] Romberg and Barnes, *op. cit.*, p. 80.

[10] H. H. Hess, "Serpentinization: Origin of Certain Asbestos, Talc and Soapstone Deposits," *Economic Geology, 28* (1939), 643–657.

[11] N. L. Bowen, "Magmas," *Geol. Soc. Am. Bull., 58* (1947), 263–280.

and for the Coal Creek mass, it looks equally impossible for sufficient water to have been picked up during the emplacement of the peridotite to form the serpentine.

The Town Mountain granite, as pointed out above, is probably later than the serpentine and could possibly have furnished the solution for serpentinization of the peridotite. However, the intervening rock shows little if any granitization and few aplites, pegmatites, and quartz veins come near to the serpentine. At least half of the serpentine is more than 2 miles from the nearest outcropping granite mass, and a regional gravity survey indicates that there is little probability of granite being as near beneath the serpentine. It, therefore, seems unlikely that serpentinization was influenced by the granite.

The production of serpentine within the zone of ground-water circulation has been little considered, except for serpentine of the type found along the Balcones fault zone.[12] If the Coal Creek mass is a result of ground-water alteration, then there should be a limit to the depth to which the serpentine extends. The depth to which the serpentine extends cannot be observed directly, but an examination of the gravity field indicates that it is bottomed at a relatively shallow depth. When peridotite changes to serpentine, a large volume increase theoretically takes place, and in many deposits there is little evidence of the deformation that should accompany such a change. However, where serpentinization is a near-surface phenomenon, there is little confining pressure and the serpentine could expand upward with a minimum of shearing.

GRAVITY OBSERVATIONS

The gravity observations were corrected in the usual manner, and a contour map was drawn from them (Fig. 2). The expected error in the observations is less than one-tenth milligal, so that whatever errors are in the map are due to sparseness of data and to the contouring rather than instrumental errors. No terrain corrections were made; since the anomalies observed were of the order of several milligals, it was not considered that errors due to terrain would affect the conclusions.

Qualitative Interpretation of Gravity Data.—The first feature to be noticed on the map is a fairly strong gradient rising to the north and east. The geological map (Fig. 1) shows granite and various Cambrian sedimentary rocks southwest of the serpentine mass; and beyond the map to the south and west, granite is dominant. The granite and the sediments are lighter than the schist and gneiss, and this may account for the lower values of gravity to the south and west. No regional gradient has been subtracted from the values used in making the contour map, even though a fairly well-defined regional gradient appears.

The most obvious anomaly on the map is the strong positive closure north of

[12] J. T. Lonsdale, "Igneous Rocks of the Balcones Fault Region of Texas," *Univ. Texas Bull. 2744* (1927), 139–141.

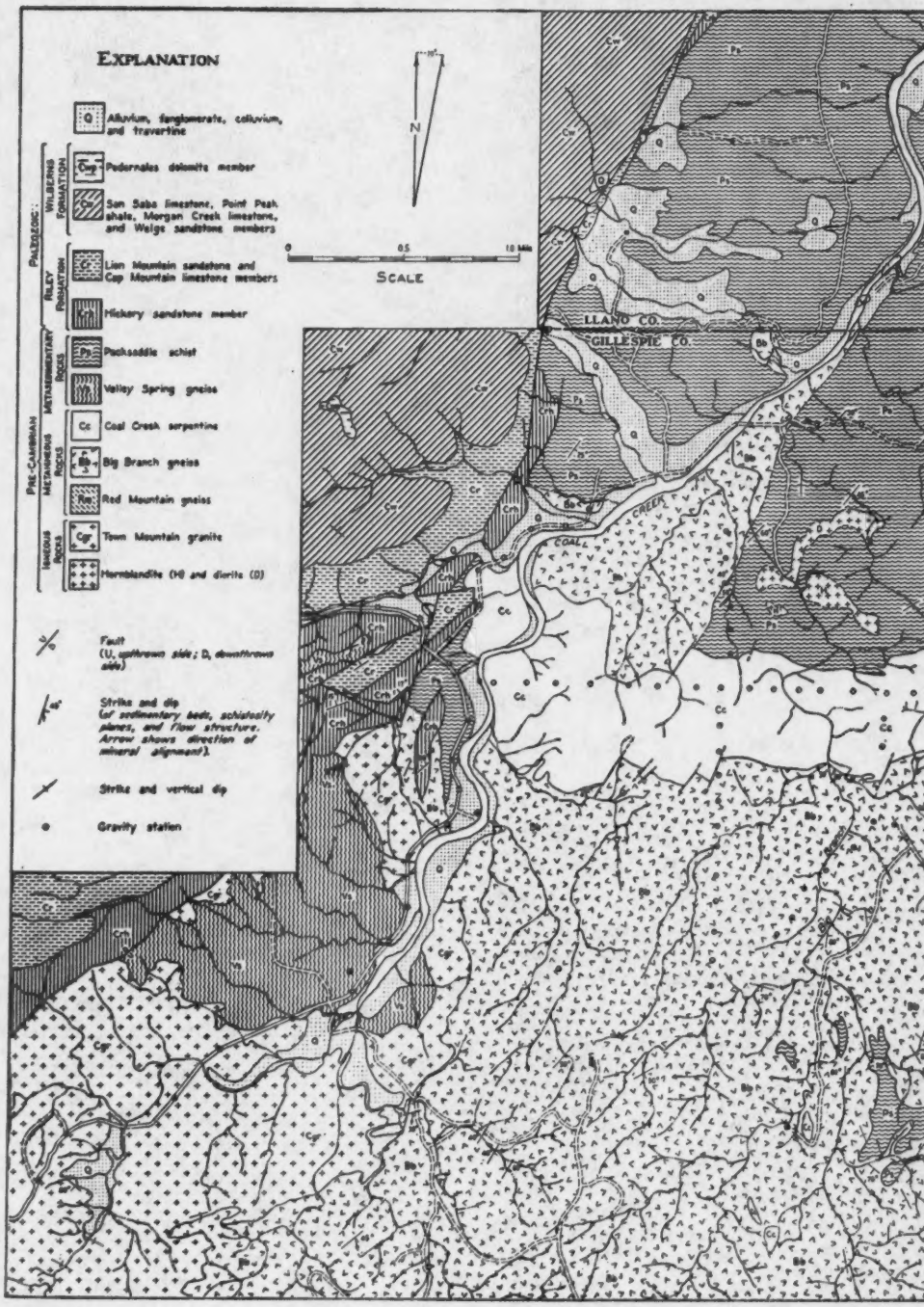

FIG. 1. Geologic map, Coal Creek serpentine, G

ntine, Gillespie and Blanco Counties, Texas.

the serpentine mass. The position of this closure corresponds to the position of the Packsaddle schist, as shown on Figure 1. As the schist is more dense than either the gneiss or the serpentine, it is normal for it to cause a positive gravity anomaly.

The serpentine mass appears in turn to be associated with a negative anomaly, contrasting sharply with the schist anomaly to the north and less sharply with the gravity values to the south over the gneiss. This is natural because the gneiss, while heavier than the serpentine, is lighter than the schist.

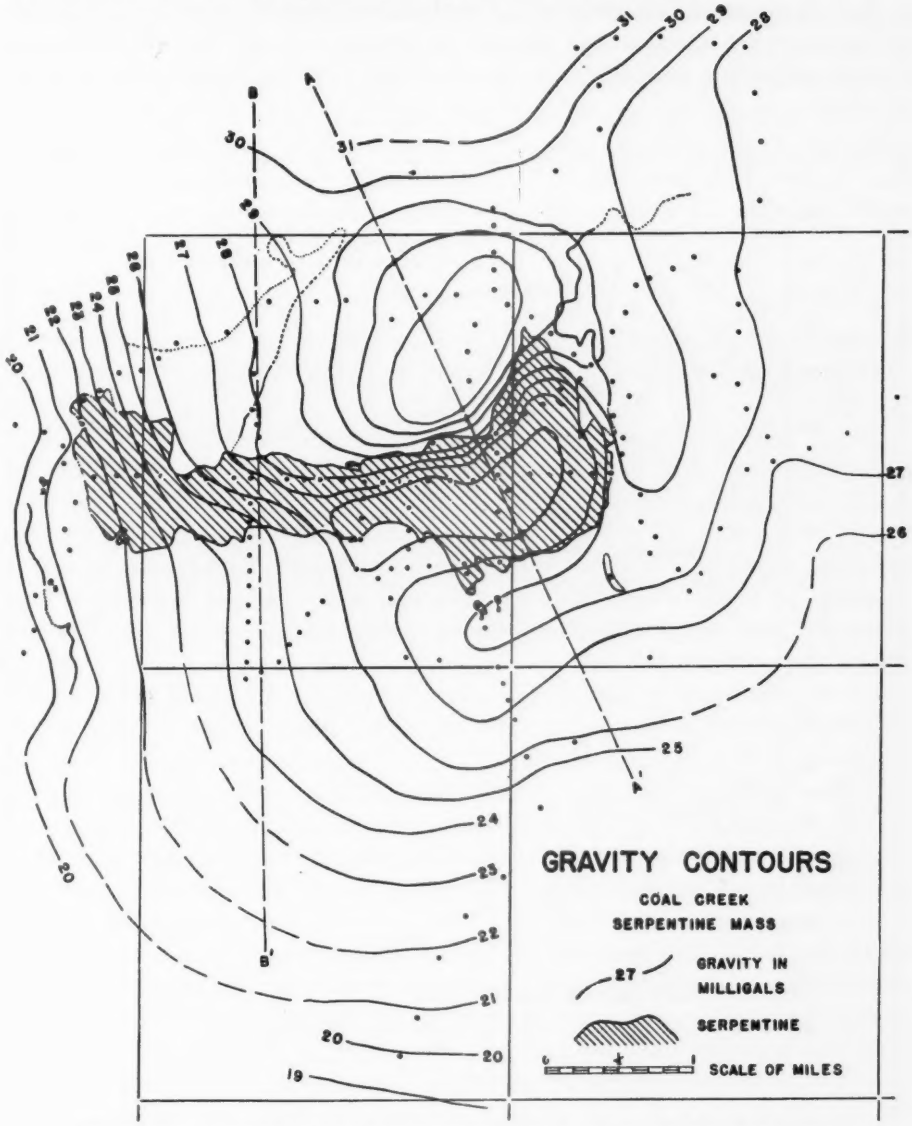

FIG. 2. Gravity map, Coal Creek serpentine, Gillespie and Blanco Counties, Texas.

The gravitational effects of schist and serpentine can be seen in Figure 3, which shows two north-south profiles of the observed field through the east and the west ends of the serpentine mass. (The locations of these profiles are shown as the lines AA' and BB' in Figure 2.) The profiles show a general slope to the south, so that a regional gradient may be assumed for the purpose of measuring the magnitude of the anomalies more accurately. The assumed gradient is shown by dotted lines and is roughly the same on both profiles.

It is to be noted that the gravitational anomalies at the west end of the serpentine mass are less than half as large as those at the east end. This indicates that the serpentine probably extends to less than half the depth at the west end

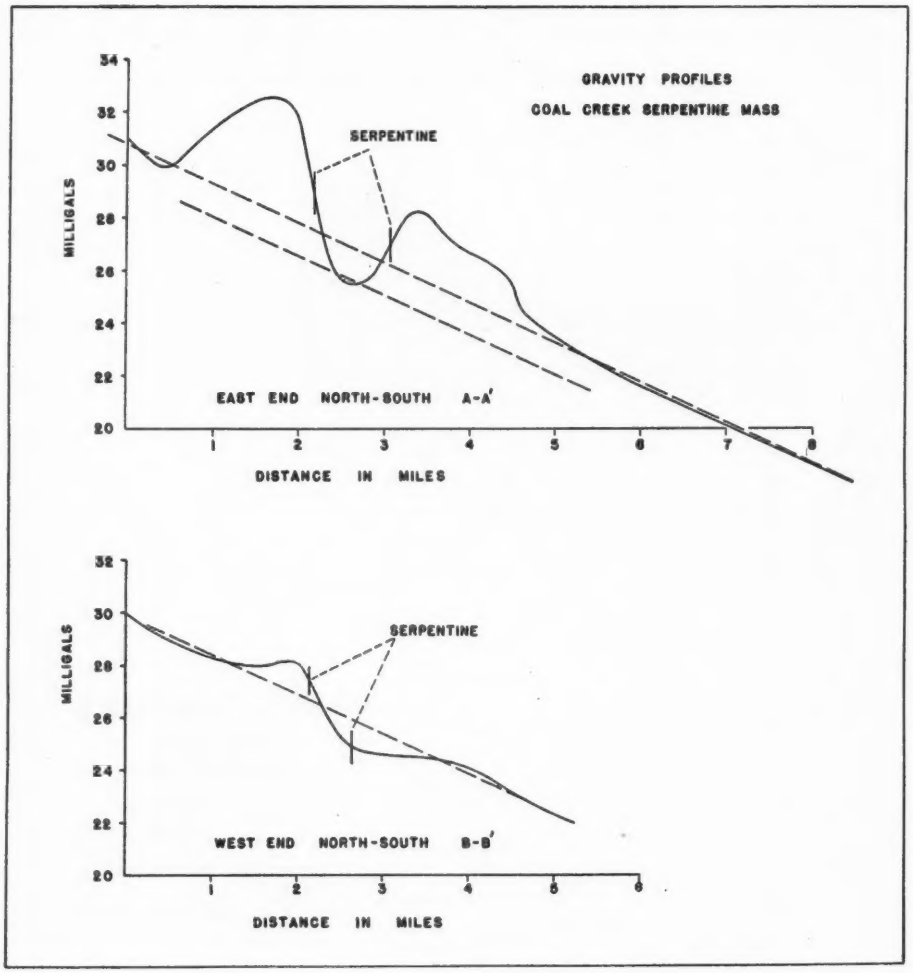

FIG. 3. Gravity profiles, Coal Creek serpentine, Gillespie and Blanco Counties, Texas.

of the mass than at the east. The smallness of the positive anomaly suggests that the schist is almost gone; this is confirmed by the geological map. In addition, the position of outcrop of the serpentine is offset from the middle of the negative anomaly, suggesting that the serpentine present dips southward. The same thing is true of the schist anomaly. On the cross section AA', over the main part of the structure, the center of the anomaly and the center of the outcrop coincide; this throws doubt on the possibility that the east end of the serpentine may be dipping.

Two-Dimensional Assumption.—As a first step toward a quantitative interpretation of the gravity data, let us assume that the contact between the gneiss and the serpentine is straight and extends infinitely east and west. If this is true, the depth to which the serpentine extends can be computed from the change in the observed values of gravity, assuming that the density difference between the two substances is known. The density difference is $2.75-2.55=0.20$ gm/cm^3, and the gravitational anomaly (Fig. 3) is about 3.5 milligals. When these data are used in the Bouguer equation

$$\Delta g = 2\pi ksz$$

for the attraction of an infinite, uniform, horizontal layer (Δg=gravitational acceleration, s=density difference, z=depth, and k is the gravitational constant), they yield $z=1{,}400$ feet.

Since the dimensions of the serpentine are not infinite, this depth is, of course, too small, and we shall consider a better assumption later. If the density used for the serpentine is too large (six surface samples average 2.48 instead of 2.55 gm/cm^3), the computed depth is too great.

A second estimate for the depth of the serpentine may be made by using the gravity difference between the schist and the serpentine, which is 5.5 milligals. Used in the Bouguer equation, this value shows a depth of 1,100 feet. This estimate is, of course, less valuable than the previous one (1,400 feet) since the assumption of infinite extent is even further from the truth. However, the schist itself appears to cause a positive closure on the contour map of about 3.5 milligals with respect to the gneiss around it; with a density contrast of 0.2 this indicates a depth of 1,400 feet, the same as the depth of the serpentine. It is thus reasonable to assume that the schist and the serpentine both extend to a relatively shallow depth. The serpentine is apparently surrounded, and presumably underlain, by something denser than itself, and the schist by something less dense; this is apparently the gneiss.

If the same kind of computation is made for the west end of the serpentine mass, using an anomaly of about 1.2 milligals, the depth is found to be 500 feet.

Assumption of Finite Dimensions.—The next step is to see if it is possible to refine the assumptions from two-dimensional to three-dimensional, considering the known geology and the general aspect of the data. Assuming the eastern end of the serpentine and schist to be upright cylinders should give a better result, since on the surface they are almost as broad as they are long.

Using the formula for the attraction of an upright cylinder (see Appendix, equation (1)), we compute the depth from the gravity anomaly of 3.5 milligals. This gives a result $z_2 = 2{,}000$ feet, instead of 1,400 feet as previously estimated. There is no reason for assuming that this depth is in error one way more than another because of the geometric assumptions (except as the schist anomaly may reduce the apparent serpentine anomaly), so the only sources of gross error in it are the gravity difference and the density difference. It may therefore be assumed that the depth of 2,000 feet represents the actual depth of the bulk of the serpentine mass, unless some unknown geological feature is involved.

A similar assumption for the Packsaddle schist gives a probable depth of 1,650 feet. The schist depth changed less than that of the serpentine because of the greater radius ($a = 1.5$ km) used in the computation.

A factor which might influence the sizes of the schist and serpentine anomalies is their interference with each other, which might tend to make both anomalies seem smaller than they really are. To estimate the magnitude of this effect, we compute the downward attraction of each of the assumed cylinders at the center of the upper surface of the other, assuming also that their sides are in contact, according to the formulas for the attraction of a cylinder, as listed by Romberg and Barnes.[13] The result is that the attraction of the assumed serpentine cylinder at the center of the assumed schist cylinder is less than 0.1 milligal, and the attraction of the schist cylinder at the center of the serpentine is less than 0.2 milligal. These effects are not large enough to modify the computations appreciably.

Dip of Serpentine.—As evidence of the dip of the serpentine, we have two qualitative facts from profile AA'. First, the serpentine anomaly is approximately centered between the boundaries of its outcrop. Second, the value of gravity at each boundary is about halfway between the maximum on one side of the boundary and the minimum on the other. Both these facts indicate that the contacts between the serpentine and the rocks on either side of it are nearly vertical.

The slope of such a contact can be computed for the case of a contact between two masses that are horizontally infinite by measuring the gravity value at the contact with respect to the maximum on one side and the minimum on the other (see Appendix, equations (3)–(7)). Thus if the gravity value at the contact is halfway between the maximum and the minimum gravity value, the contact is vertical. Though in the present case there is not sufficient detail to encourage computing the slope accurately, the measurements taken from the graph yield a dip northward of 83°, $\pm 5°$, for both contacts. This contradicts the geological data.

Possibility of Peridotite under Serpentine.—The geophysical evidence for peridotite under the serpentine mass can be evaluated only under the assumptions that there are no large unknown masses present except peridotite, and that the observed masses of gneiss, granite, and schist are simple in shape. Without

[13] Romberg and Barnes, *op. cit.*, p. 91.

this assumption it is, of course, impossible to speculate on the meaning of any gravitational anomaly, since any force field may be caused by an infinite number of different geological configurations. With the assumption, however, we may set limitations on the existence of peridotite. If the masses of gneiss, schist, and granite are present as computed in the preceding section, the peridotite can only be a thin feeder or a uniform level sheet, as these forms would not affect the

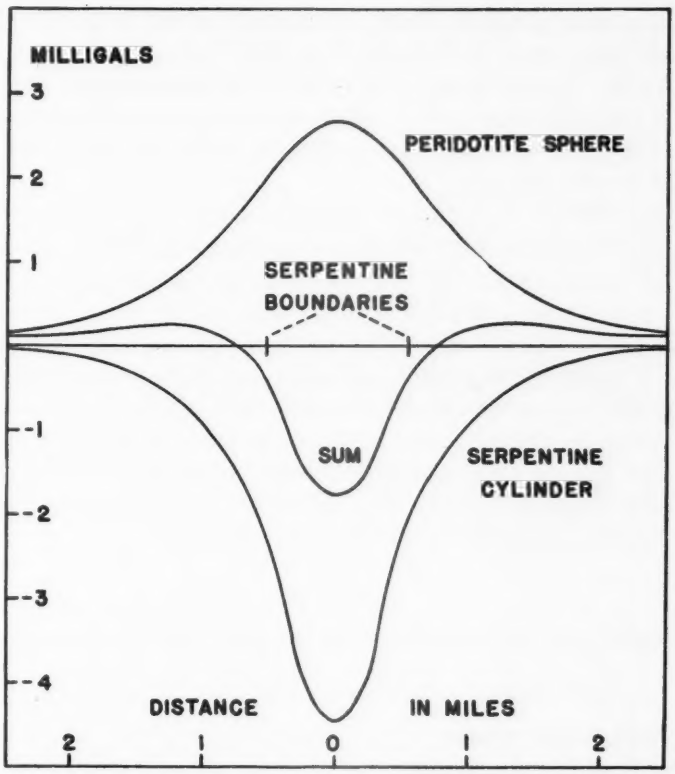

FIG. 4. Computed profiles showing possibility of peridotite under serpentine.

gravitational field. However, such forms are not geologically probable. It is more likely that the peridotite, if it is present, is in some form whose dimensions are comparable to those of the serpentine itself. If this is the case, of course, our previous idea of the gneiss, schist, and serpentine must be modified so as to leave the gravitational field the same as before. It is also likely, in view of the symmetry of the serpentine anomaly, that the peridotite is directly underneath the serpentine and not off to one side. In addition, the bulk of the peridotite has to be under the east end of the serpentine mass, as there is very little disturbance to hide peridotite under the serpentine on the west end.

The gravitational field, then, imposes the following conditions on the perido-

tite-serpentine combination, according to profile AA' of Figure 3: (1) The peridotite is directly under the serpentine. (2) The gravity effect of the combination must resemble the gravity effect assumed for the serpentine itself before the peridotite was considered. That is, the combined effect must be about 2 milligals less at the center of the serpentine than it is at the outer edges of the gneiss and schist anomalies. This condition can be expressed analytically, of course, and will have a variety of permissible solutions, somewhat limited by the condition that the gradients of the combined profile must resemble the observed gradient. (If the serpentine were very deep, its negative anomaly would be much larger and not so sharply cut off.) The combination of a serpentine cylinder 3,300 feet deep, with a peridotite mass underneath it with a radius of 2,900 feet, fulfills the conditions, giving (see Fig. 4) a resultant gravity profile which resembles the observed anomaly over the serpentine.

Mass of Serpentine.—A minimum estimate for the mass of serpentine present can be arrived at by measuring the area and multiplying by the estimated depth. This depth, of course, varies, and may probably be taken to be 2,000 feet in the eastern part of the mass and 500 feet in the western. Dividing the area roughly into two parts, and multiplying each by its estimated depth, yields a mass of 10^{10} metric tons. If peridotite is present under the serpentine, the serpentine will be deeper at the east end, so the estimate of mass will be a minimum.

The mass may also be estimated by the integrating of the anomalous figure,[14] but the method was not used because it would have necessitated subtracting the regional gradient from the gravity map and did not promise results that would be much more accurate than the straight geometric method.

APPENDIX

Heiland[15] gives, for the attraction of an upright cylinder at a point on its axis,

$$\Delta g = 2\pi ks(z_2 - z_1 + \sqrt{a^2 + z_1^2} - \sqrt{a^2 + z_2^2}), \qquad (1)$$

where a = radius of the cylinder,
z_1 = depth to top of cylinder,
z_2 = depth to bottom of cylinder,
k = gravitational constant,
s = density contrast.

If we set $z_1 = 0$ and solve for z_2, we get

$$z_2 = B(2a - B)/2(a - B) \quad \text{where} \quad B = \Delta g/2\pi ks. \qquad (2)$$

Then if a is assumed to be 0.86 km (2,820 feet), z_2 comes out to be 2,000 feet.

To measure the dip of an interface between two masses with horizontal

[14] Sigmund Hammer, "Estimating Ore Masses in Gravity Prospecting," *Geophysics*, X (Jan., 1945), 50.

[15] Heiland, *Geophysical Exploration* (New York: Prentice-Hall, 1940), p. 147.

boundaries and infinite horizontal dimensions, we begin with Heiland's equation[16] for the attraction at various locations above such an interface.

$$\Delta g = 2ks\{D\phi_2 - d\phi_1 - (x \sin i + d \cos i)[\sin i \ln (r_2/r_1) + \cos i(\phi_2 - \phi_1)]\}, \quad (3)$$

where i = dip of interface,
D = depth to bottom of interface,
d = depth to top of interface,
r_1 = distance to top of interface,
r_2 = distance to bottom of interface,
φ_1 = angle between r_1 and horizontal,
φ_2 = angle between r_2 and horizontal,
x = horizontal distance to top of interface.

If $d=0$, then $\varphi_1=0$, and we have

$$\Delta g = 2ks\{D\varphi_2 - (x \sin i)[\sin i \ln (r_2/r_1) + \cos i]\}. \quad (4)$$

Now if $x=0$, and since $\lim_{x\to 0} x \ln (r_2/r_1)=0$,

$$\Delta g_x = 2ksD\pi. \quad (5)$$

If x is infinite, then for the asymptotic value of Δg, we can write the Bouguer equation

$$\Delta g_{max} = 2ksD\pi. \quad (6)$$

The ratio of these yields φ

$$\varphi = \Delta g_x/\Delta g_{max}. \quad (7)$$

[16] Heiland, *op. cit.*, p. 153.

PROPAGATION OF ELECTROMAGNETIC WAVES IN EARTH*

O. C. HAYCOCK,† E. C. MADSEN,† AND S. R. HURST†

ABSTRACT

The successful use of radar for locating objects has led the authors to consider the possibility of using it to determine discontinuities within the earth. Knowledge of the propagation characteristics of waves in the earth is required before such a development might be undertaken.

The present article reviews the literature in this field and reports experiments in which the velocity, attenuation, and wave length of electromagnetic waves in certain earthy materials were measured. The conclusion describes the possibilities of such a development based on the experimental results.

INTRODUCTION

The use of electromagnetic waves in detecting discontinuities beneath the earth's surface has been the goal of scientists and engineers for many years. Various methods have been devised, most of them relying on the change in field configurations over the ground caused by the effect of the ground and bodies in it. With the great success of radar in the recent war, a method employing the detection of a signal reflected from discontinuities of earth material was suggested. A most desired development would be that of a device operating on the principle of radar which could detect not only the presence of an underground discontinuity, but further determine its direction, distance, and relative magnitude. Surely the usefulness of such a device would be limitless. Some of the more obvious uses would be the location of underground bodies of water, ore deposits, oil deposits, and geophysical mapping in general.

One would correctly suspect that the development of such a device would involve a great deal of research in a number of fields. Preliminary to the development of this device would be a determination of the possibility of propagation of electromagnetic waves to useful distances into the earth. Inasmuch as this determination would cover a rather basic field, it was felt that it was an important subject for an investigation.

The investigation of the propagation characteristics of radio waves in various earth materials was composed of two phases that were very closely related: the attenuation and the velocity of propagation.

In general, the earth has been assumed to be a good conductor in the study of propagation. As evidence of this fact, it will be noted that most broadcast antennas are designed on this basis. However, Eve,[1] in conjunction with Keys and Lee[2], reported that their experiments at Mammoth Cave in Kentucky proved con-

* Manuscript received by the Editor, November 1, 1948.

† University of Utah, Salt Lake City.

[1] A. S. Eve, "Absorption of Electromagnetic Induction and Radiation by Rocks," *Amer. Inst. of Mining and Met. Eng. Tech. Pub. 316* (1930).

[2] A. S. Eve, D. A. Keys, and F. W. Lee, "The Penetration of Rock by Electromagnetic Waves at Audio Frequencies," *Proc. I.R.E., 17* (November, 1929), 2072.

clusively that electromagnetic waves could be propagated through the earth. There they found that reception of standard broadcast stations was possible with an overburden of about 300 feet. The possibility of an air path through the entrance to the cave was investigated by carrying a portable receiver from the entrance of the cave. The signal was found to decrease greatly as the distance from the entrance and the thickness of the overburden increased. Approximately 2,000 feet in from the entrance, the thickness of the overburden decreased and the signal was again detected. This, coupled with the fact that there were no metallic conductors whatever coming into the cave, gave assurance that the signal was transmitted through the earth.

Joyce[3] reported that Eve and Keys had previously attempted to detect signals underground in a railroad tunnel near Montreal. Their results were in doubt as there were wires and rails running through the tunnel that could have carried the signal. One definite result, however, was that higher frequencies were attenuated more than the lower frequencies.

Joyce further reported that work was done with 500 cycles in Mammoth Cave with a detection of the signal through nearly 900 feet of overburden. At this low frequency, it is quite likely that the signal at the receiver was in good part the result of the induction field as well as the radiation field. Using the theoretical equations for attenuation by Maxwell, Sommerfeld, and Zenneck, Joyce plotted curves of absorption versus frequency, indicating that propagation was possible to some extent and that the equations of all three workers were mainly in agreement with the experimental results using 500 cyles.

Feldman,[4] Smith-Rose and McPetrie[5,6] performed several experiments in order to find the various electrical properties of earth materials. Smith-Rose plotted curves of earth currents versus depth of penetration using these properties in Maxwell's equations. These curves indicated that the attenuation was rather rapid and increased with frequency.

Terman[7] indicated that the depth at which earth currents become negligible is from 5 to 10 feet in the short-wave range and from 50 feet up for the broadcast frequencies and lower frequencies. He further noted that the penetration depth of a wave would be little affected by surface effects such as moisture due to a single rainfall. Heiland[8] suggested that radio-frequency waves would be useful in locating subsurface objects up to depths of only 15 to 20 feet.

[3] J. W. Joyce, "Electromagnetic Absorption by Rocks," *U. S. Bur. of Mines Tech. Paper 497* (1931).

[4] C. B. Feldman, "The Optical Behavior of the Ground for Short Radio Waves," *Proc. I.R.E.*, 18 (June, 1933), 764.

[5] R. L. Smith-Rose, "Electrical Measurements on Soil with Alternating Currents," *Jour. of Inst. Elec. Engrs.* (London) (August, 1934), 221–237.

[6] R. L. Smith-Rose and J. S. McPetrie, "The Attenuation of Ultra-short Radio Waves Due to the Resistances of the Earth," *Proc. Phys. Soc., 43* (London), (September, 1931), 592–620.

[7] F. E. Terman, *Radio Engineers Handbook* (New York: McGraw-Hill Book Co., 1943), 708–709.

[8] C. A. Heiland, *Geophysical Exploration* (New York: Prentice-Hall, Inc., 1940). 310–314, 657–667.

Kerwin[9] indicated that penetration was sufficient to warrant the use of field-strength measurements of local broadcast signals to detect changes in the earth's structure. Abnormal changes in field strength would be an indication of the presence of bodies near the surface possessing different propagation properties. He achieved some success in his investigations.

Wadley[10] investigated the problem of radio communication in African gold mines and found that communication was only feasible at distances up to one mile in dry rock using frequencies from 100 to 300 kc. A disadvantage at these frequencies was the length of antenna required.

McIlwain and Wheeler[11] reported that in one of their experiments they received a 2 mc signal through 600 feet of overburden during an unusual dry season. During the wet season, they found that the result could not be confirmed. In another experiment, two holes were drilled. A receiver was lowered in one hole and a transmitter in the other. In repeating the experiment in various locations, they found that the attenuation varied considerably with the type of material and concluded that underground propagation was commercially impractical for use in geophysical explorations. However, they suggested that water could be located in very dry areas by using this method. They also reported that Fritsch and Doborzynski had achieved considerable success in underground propagation experiments in Europe.

The literature, therefore, indicates that propagation of electromagnetic waves in the earth is possible to some degree. However, further information regarding the propagation characteristics of various earth materials is greatly to be desired.

METHODS OF PROCEDURE

In order to measure the attenuation and velocity of propagation of electromagnetic waves in the earth for various frequencies, three methods were tried: (1) buried transmission line, (2) buried dipole antennas, (3) transmission through overburden of mine tunnel.

Buried Transmission Line.—The first method was to bury a two-wire transmission line, apply a signal at one end, and measure the voltage across the line at various points. This was considered to be desirable in order to detect the presence of standing waves on the line under open- and short-circuit terminations. From these measurements, both attenuation and velocity of propagation could be determined.

Of several buried transmission lines tried, one gave very satisfactory results. The line was 160 feet long of enameled No. 14 solid copper wire with 3-inch spac-

[9] L. Kerwin, "Use of the Broadcast Band in Geologic Mapping," *Jour. of App. Phys.*, *18* (April, 1947), 407.

[10] T. L. Wadley "Underground Communication by Radio in Gold Mines on the Witwatersrand," *So. African Council for Scientific and Industrial Research, Report T.R.L. 3* (November, 1946).

[11] K. McIlwain and H. A. Wheeler, "The Propagation of Radio Waves Through the Ground," pre-print summary, private communication (February, 1948).

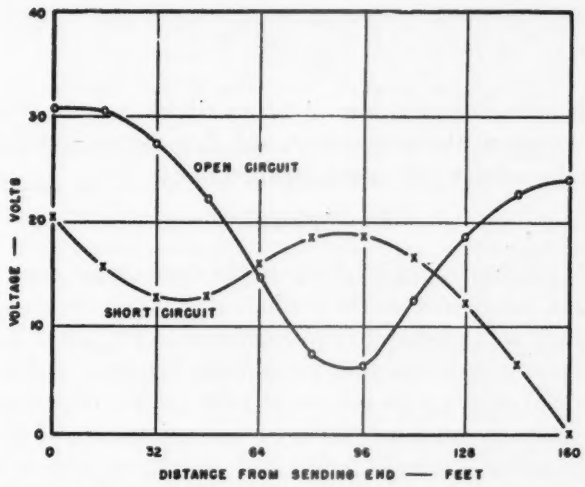

FIG. 1. Voltage measurements on buried transmission line at 350 kc.

ing and was buried at a depth of 18 inches in slightly damp, sandy soil. Chimney openings, approximately 6 inches by 4 inches, were placed every 16 feet so that voltage readings could be taken. A 100-watt variable frequency transmitter was used as signal source and fed to the line with a 50-ohm coaxial cable. The results are plotted in Figures 1 and 2.

Although the power at any point on the transmission line is equal to the product of the voltage, the current, and the cosine of the phase angle between them at that point, in high-loss lines the power level is approximated very closely by using the product of the voltage and current alone. According to standard books on transmission lines, the current on an open-circuited line at any point is

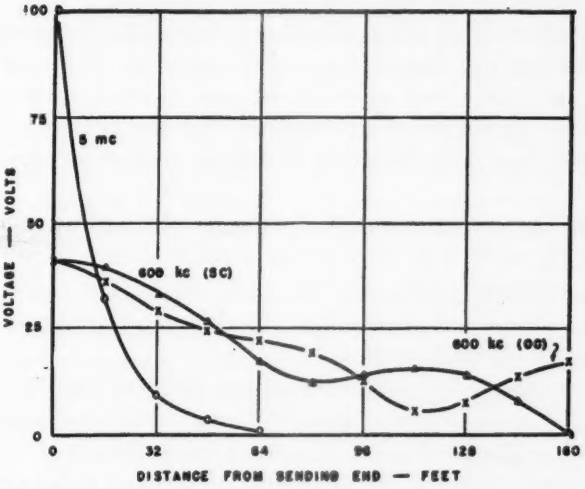

FIG. 2. Voltage measurements on buried transmission line at 600 kc and 5 mc.

$$I = \frac{E_r}{Z_o} \sinh \gamma l,$$

where l is the distance measured from the open circuit, γ is the propagation constant, E_r is the voltage at the open circuit, and Z_o is the characteristic impedance of the line. Also the voltage on a short-circuited line is

$$E = I_r Z_o \sinh \gamma l.$$

Since the ratio of the short-circuit voltage to the open-circuit current at the same point is a constant, it follows that the product of the open-circuit voltage and the short-circuit voltage is approximately proportional to the power level.

The relative power level was thus found from Figures 1 and 2. The attenuation was determined to be 7.5 db per 100 feet for 350 kc, 11.7 db per 100 feet for 600 kc, and about 62 db per 100 feet for 5 mc. From the standing waves formed on the transmission line, the wave length and velocity of propagation was found to be nearly one-tenth of that in the air.

Impedance-bridge measurements on the buried line over the same frequency range indicated that the input impedance to the line was mostly resistive and had a magnitude of 50 to 60 ohms.

Buried Dipole Antenna.—Another system for determining the attenuation of electromagnetic waves in the earth was the method of burying a simple dipole antenna with horizontal polarization and feeding the antenna directly at the center with a coaxial transmission line. A similar antenna, with the coaxial line connected to a sensitive receiver having a signal-strength indicator and placed at various distances from the transmitting antenna, seemed to be a promising possibility.

In order to test this system, several half-wave dipole antennae were constructed to operate underground, and at a frequency of 20 megacycles in order that the antennae could be physically short. Assuming the wave length in the ground to be one-tenth of that in air, as determined at the frequency of 600 kc, the physical length for a half wave length was 30 inches. The antennae were constructed of No. 14 enameled solid copper wire and center fed with a coaxial cable. The connections were insulated to reduce conduction currents to a minimum.

The depth of the antennae was also 30 inches or a half wave length in an attempt to make the earth and air juncture a point of high impedance and were buried in the same slightly damp, sandy soil as before. The 100-watt transmitter was again used as the signal source. No difficulty was experienced in loading the transmitter with the buried antenna.

Measurements showed a large attenuation with increase in distance. However, a single-wire antenna above ground showed considerable signal in the air. In an attempt to make the signal indication a measurement of only the wave in the earth, the transmitter was placed in an underground cellar with the antenna

buried in the floor. The entire battery-operated receiving apparatus was also buried, leaving a small hole for reading the signal strength indicator. However, the relative position of the operator had some effect upon the indicated signal strength.

The results of this test, along with other similar tests, led to the conclusion that a considerable portion of the energy was coming out of the ground near the transmitter, being propagated through the air, and that the ground wave associated with the air wave was mainly responsible for the signal received in the ground. It was felt, therefore, that the data obtained were unreliable for determining attenuation in the ground.

Transmission Through Overburden of Mine Tunnel.—In an attempt to eliminate the possibility of an air path between the transmitter and receiver, it was decided to find a situation where transmission must necessarily be through the earth. Abandoned mine tunnels were considered to offer the best solution to the problem with the transmission path to be from a tunnel to the surface.

A transmitter was placed inside the tunnel and the receiving apparatus on the surface. Measurements were first attempted with the transmitter 150 feet from the mouth of the tunnel, using a 24-foot dipole antenna suspended lengthwise in the bore. The rock was dry at this location. The receiver was located directly overhead with about 60 feet of overburden. Strong signals were received at frequencies up to 7.5 mc and readable signals at 18.5 mc. Signal strength was checked at the tunnel mouth with some signal at 625 kc but none detectable at 18.5 mc. Since the signal strength at the overhead position was much stronger than that at the tunnel mouth, propagation was indicated to be through the rock. More will be said later about this subject. About 50 feet farther into the tunnel, very wet andesite was encountered. Measurements were attempted at frequencies ranging from 350 kc to 18.5 mc with practically no signal received through the overburden. The overburden was approximately 100 feet.

As a matter of secondary interest, detection of a local broadcast signal (1,160 kc) was undertaken in the tunnel using the battery-operated receiver and loop antenna. Signal was lost at the point where previous measurements had been attempted in the damp area. However, upon progressing farther into the tunnel, dry quartzite was encountered and a strong broadcast signal was noted. The overburden at this point was 130 feet and the distance from the entrance about 700 feet. An audible signal was received to a point where the overburden was nearly 400 feet thick.

Attenuation measurements were again attempted in the dry quartzite with the transmitter in the tunnel and the receiver on the surface. Frequencies of 355 kc and 710 kc gave very good results. One very weak reading was noted with 3.15 mc at the point of minimum overburden (in the bottom of a gully). No further readings were obtained at 3.15 mc or at higher frequencies. No signal was received at the mouth of the tunnel, proving beyond doubt that propagation was only through the overburden.

Calibration of the receiver was accomplished in the laboratory by using a standard signal generator.

Figure 3 shows how the signal strength varied with thickness of the overburden. Correcting the relative attenuation readings for the inverse law of distance, the attenuation due to the medium was found. The point of minimum overburden was used as the reference point. These calculations neglect the presence of an induction field which assumption seems reasonable. The attenuation in db

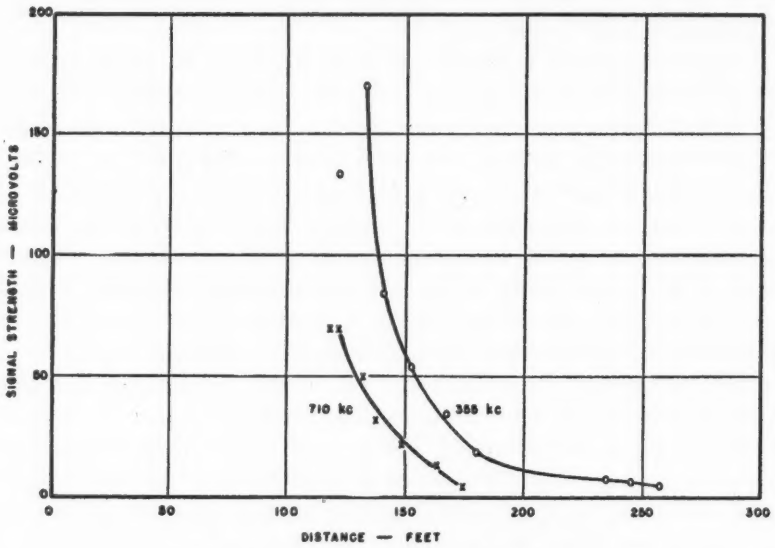

FIG. 3. Variation of total signal strength.

below the reference level is shown in Figure 4. The attenuation at 355 kc is seen to be in the order of 16 db per 100 feet which corresponds to 0.53 db per meter. The attenuation at 710 kc is also seen to be in the order of 40 db per 100 feet which coresponds to 1.3 db per meter.

At 3 mc only one satisfactory reading was obtained and this was through the minimum overburden. However, from the radiated power and assuming the same radiation pattern as for the lower frequencies, it was possible to estimate the attenuation as 1.8 db per meter. The attenuation was too great for any transmission at higher frequencies.

Published data on the electrical constants of various earth materials show some variation. For example, reasonable values of dielectric constant and permeability for quartzite were found to be 6.6 and 1.0 times the values in vacuum respectively.[12] This results in the values of 5.83×10^{-11} farads per meter for the

[12] F. Birch et al., "Handbook of Physical Constants," *Geol. Soc. Amer. Special Paper 36* (1942).

dielectric constant and 1.26×10^{-6} henrys per meter for the permeability. Reasonable bounds on possible conductivities were 3×10^{-5} and 10^{-1} mhos per meter,[13] the actual value depending on the moisture content. Substituting these values into equation (5) (see Appendix) at 700 kc, results in the highest probable attenuation of 7 db per meter and the least probable attenuation of 0.02 db per meter. These may be compared with the experimental value of 1.3 db per meter for attenuation.

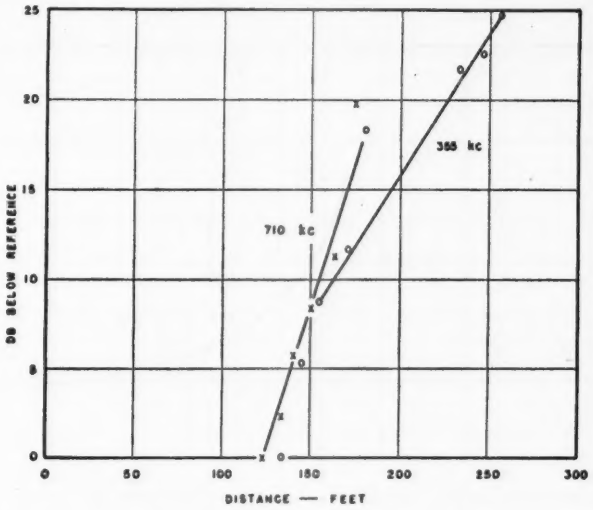

FIG. 4. Attenuation of electromagnetic waves due to quartzite.

CONCLUSION

A consideration of attenuation, present-day transmitter technique, and antenna-length limitations, indicates that frequencies from 300 to 1,000 kc are the most practical for through-the-earth propagation. The problem seems to be one of getting sufficient energy into the ground and beamed so that the direction of a reflection wave could be accurately determined. The problem of a very directional radiation pattern of an antenna at these frequencies is very apparent.

Application of ordinary radar techniques for the location of underground discontinuities, such as water strata or ore bodies, is seen to be doubtful at 300 to 1,000 kc because of the short distances that are involved. The power of any reflected signal would be proportional to the effective area of the antenna, the area causing the reflection, and inversely proportional to the fourth power of the distance involved even if there were no attenuation due to the medium. The pulse duration would also have to be very short in order to be able to recognize any reflected pulse since the time for the reflected pulse to return would be very short

[13] C. A. Heiland, *op. cit.*, p. 627.

for the effective distance. Using a velocity of propagation one-tenth that in air, the wave would travel nearly 100 feet per microsecond, leaving a minimum distance of about 50 feet for a one microsecond transmitted pulse length.

Consideration of pulse length and oscillation period also discourage ordinary pulsing. A pulse length of one microsecond at 1,000 kc would allow time for only one complete cycle of oscillation. If 100 db total attenuation from transmitter to receiver were assumed (justified from radar practice), the maximum distance from which signals could be detected in dry quartzite is shown in Figure 5.

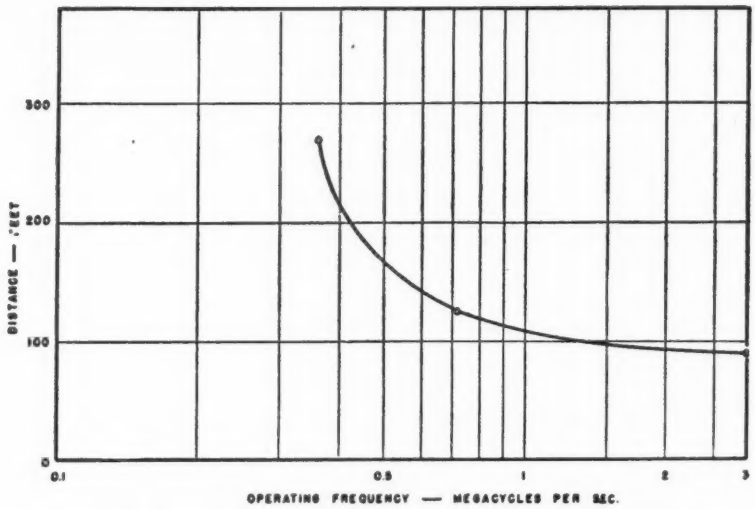

FIG. 5. Maximum receivable distance in dry quartzite, giving total reflection with 100 db allowable attenuation.

Another method that might possibly be used would utilize a frequency-modulated transmitter which would enable the determination of the phase shift between the transmitted wave and the reflected wave. The amount of shift would be an indication of the distance to the point of reflection. The velocity of propagation would have to be known. This method shows promise but will have to wait for further investigation.

APPENDIX

THEORY

Maxwell's equations for electromagnetic waves are general in that they hold for any medium, conducting or nonconducting, in vacuum or in dielectric or magnetic materials. They may be found in any standard book on wave theory. More usable equations may be developed from Maxwell's equations from which values may be obtained for the propagation constants.

In earth materials there are no isolated charges, and it follows from Maxwell's equations that with the use of standard symbols

$$\frac{\partial^2 E}{\partial x^2}+\frac{\partial^2 E}{\partial y^2}+\frac{\partial E}{\partial z^2}=\mu\sigma\frac{\partial E}{\partial t}+\mu\epsilon\frac{\partial^2 E}{\partial t^2}. \quad (1)$$

For the present purposes, the concern is with a transverse electromagnetic (TEM) wave propagating in the positive z direction and polarized in the xy plane. The differential equation will be satisfied with a function describing propagation in the z direction as $e^{j\omega t-\gamma z}$ where γ is the propagation constant. Then

$$E = Ee^{j\omega t-\gamma z}. \quad (2)$$

Since the field distribution in the transverse plane must satisfy Laplace's equation according to Ramo,[14] then

$$\frac{\partial^2 E}{\partial x^2}+\frac{\partial^2 E}{\partial y^2}=0. \quad (3)$$

It follows that substituting equation (2) into equation (1) that

$$\gamma = j\omega[\mu\epsilon(1+\sigma/j\omega\epsilon)]^{1/2}. \quad (4)$$

In general, the propagation constant will have both a real and an imaginary component known as the attenuation constant α and the phase shift constant β respectively. Further reduction of equation (4) gives

$$\gamma=\omega\{\mu\epsilon[(1+\sigma^2/\omega^2\epsilon^2)^{1/2}-1]/2\}^{1/2}+j\omega\{\mu\epsilon[(1+\sigma^2/\omega^2\epsilon^2)^{1/2}+1]/2\}^{1/2}.$$

Therefore, the attenuation is

$$\alpha=\omega\{\mu\epsilon[(1+\sigma^2/\omega^2\epsilon^2)^{1/2}-1]/2\}^{1/2} \quad (5)$$

nepers per meter and the phase shift in radians per meter is given by

$$\beta=\omega\{\mu\epsilon[(1+\sigma^2/\omega^2\epsilon^2)^{1/2}+1]/2\}^{1/2}. \quad (6)$$

These equations were found assuming only that the fields in the direction of propagation were zero. Therefore, they hold for any TEM wave whether it be in a dielectric (earth) or guided by an open, two-wire transmission line, provided that the field components in the direction of propagation are negligible with respect to the components in the transverse plane.

It also follows that these equations hold for a transmission line buried in the earth, since the field components in the direction of propagation are only those of the *IR*-drop in the line. This voltage drop can be made negligible by proper selection of conductors.

[14] S. Ramo and J. R. Whinnery, *Fields and Waves in Modern Radio* (New York: John Wiley and Sons, 1945).

A SUMMARY OF EXTENSION COURSES SUITABLE FOR FIELD-CREW TRAINING*

JAMES H. LEONARD†

ABSTRACT

A summary is made of all university and college extension courses which may be utilized in field training of geophysical crews.

The quantity and quality of work performed by field geophysical crews is determined not only by the morale and administration of the crew, but by the amount of skill and training possessed by each individual member. For this reason

TABLE 1

COLLEGES AND UNIVERSITIES IN THE UNITED STATES GIVING EXTENSION COURSES SUITABLE FOR FIELD-CREW TRAINING

1. University of Arizona, Tucson, Arizona
2. University of Arkansas, Fayetteville, Arkansas
3. University of California, Berkeley, California
4. University of Colorado, Boulder, Colorado
5. University of Florida, Gainesville, Florida
6. University of Idaho, Moscow, Idaho
7. University of Chicago, Chicago, Illinois
8. University of Kansas, Lawrence, Kansas
9. Massachusetts Dept. of Education, Boston, Massachusetts
10. University of Minnesota, Minneapolis, Minnesota
11. University of Missouri, Columbia, Missouri
12. Montana State University, Missoula, Montana
13. Rutgers University, New Brunswick, New Jersey
14. University of New Mexico, Albuquerque, New Mexico
15. University of North Carolina, Chapel Hill, North Carolina
16. North Carolina State College, Raleigh, North Carolina
17. University of North Dakota, Grand Forks, North Dakota
18. Ohio University, Athens, Ohio
19. University of Oklahoma, Norman, Oklahoma
20. Oregon System of Higher Education, Eugene, Oregon
21. Pennsylvania State College, State College, Pennsylvania
22. University of Texas, Austin, Texas
23. Brigham Young University, Provo, Utah
24. University of Washington, Seattle, Washington
25. University of Wisconsin, Madison, Wisconsin

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† Western Gulf Oil Co., Bakersfield, California.

TABLE 2

SUBJECTS IN WHICH EXTENSION COURSES MAY BE OBTAINED AND THE INSTITUTIONS WHERE THESE ARE GIVEN

GENERAL ENGINEERING
Slide Rule: 10, 13, 21

CIVIL ENGINEERING
Elementary Surveying: 2, 3, 9, 16, 21, 22, 25

ELECTRICAL ENGINEERING
Fundamentals of Electrical Engineering: 2, 5, 25
Direct- and Alternating-Current Electricity: 3, 5, 10, 13, 21
Direct- and Alternating-Current Machinery: 3, 6, 10, 25
Fundamentals of Radio: 3, 6, 10, 18, 20, 21, 25

GEOPHYSICS
Geophysical Prospecting for Oil: 21

GEOLOGY
Physical Geology: 1, 3, 4, 7, 8, 10, 12, 14, 15, 16, 17, 18, 20, 21, 23, 24, 25
Historical Geology: 1, 3, 7, 20, 21
Maps: 7
Geomorphology: 3
Elementary Mineralogy: 21, 24

MATHEMATICS
Mathematics through the Calculus: 1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 13, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25
Differential Equations: 2, 3, 4, 5, 7, 10, 20, 22, 24, 25
Empirical Formulas: 4
Nomography: 4
Statistics: 12, 18, 20
Theory of Least Squares: 4, 25
Vector Analysis: 7, 22, 25

PHYSICS
General Physics: 3, 4, 5, 8, 10, 18, 20, 22, 25
Mechanics: 3, 4, 5, 6, 7, 10, 13, 18, 20, 21, 22, 25
Wave Motion: 3

it is important that those in charge of field operations make every effort to aid crew members in establishing a background for their work. The greatest percentage of men working on field crews have had no specific training in the work. An occasional party chief maintains a training program himself; however, utilization of college and university correspondence courses provides an effective means of training.

This paper summarizes all extension courses offered in geophysics and related fields by U. S. Colleges and Universities. Only institutions which are recognized by the National University and College Extension Association are listed. While this Association is not an official accrediting agency, the strict requirements for membership are used more and more by college admission officers in evaluating courses taken by extension.

The acceptance of credits varies widely; however, most institutions within the Association permit the transfer of credits from one school to another. In general, the courses offered by these colleges and universities are acknowledged by edu-

cators to be of superior quality and less expensive than those offered by commercial private schools.

In some cases, general fields have been listed rather than specific courses. This was necessary in cases where a college or university split a subject into several courses.

The colleges and universities offering extension courses in the fields of interest are given in Table 1. In Table 2 are listed various subjects of interest and the colleges or universities (identified by the numbers corresponding to Table 1) from which extension courses in these subjects may be taken. Any correspondence should be addressed to the Extension Division Director of the school.

PATENTS*

4—ACCELEROMETER

U. S. No. 2,453,548. L. D. Statham. Iss. 11/9/48. App. 7/14/47. Assign. Statham Laboratories, Inc.

Accelerometer with Electric Strain Wires. An accelerometer having an inertia mass hinged at one end and suspended by strain-sensitive filaments fastened near the axis of the hinge.

U. S. No. 2,455,394. H. E. Webber. Iss. 12/7/48. App. 6/29/43. Assign. The Sperry Corp.

Accelerometer. An accelerometer or inclinometer having a capsule with a central hot filament and a gas in which convection currents change the filament temperature and resistance, the convection currents being disturbed by acceleration of the gas.

U. S. No. 2,457,620. C. R. Abraham. Iss. 12/28/48. App. 6/26/42.

Means and Method of Indicating Acceleration. A vacuum tube accelerometer having a collimated electron stream which is retarded and returned to a split anode, transverse acceleration of the tube being detected by shift of electron stream from one half of the anode to the other.

8—ACOUSTIC LOGGING

U. S. No. 2,451,797. A. Blanchard. Iss. 10/19/48. App. 2/17/45. Assign. Schlumberger Well Surveying Corp.

Apparatus for Producing Pressure Pulses in Boreholds. A dumbbell-type oscillator which may be lowered into a well and having two casings connected by a resilient tube, the system being oscillated at its resonant frequency through an electro-mechanical feedback.

12—ACOUSTIC MEASUREMENTS

U. S. No. 2,451,465. H. L. Barney. Iss. 10/19/48. App. 2/27/47. Assign. Bell Telephone Laboratories, Inc.

Transversal Filter. A method of modifying a signal by generating it as elastic waves in a supersonic light cell, producing variations in the light in accordance with the modification desired and summing increments of light with a photocell.

U. S. No. 2,451,509. O. M. Owsley. Iss. 10/19/48. App. 7/5/44.

Testing Device for Sound Projectors. A testing system for underwater sound transducers in which a transmitter and receiver are placed as far apart as possible in a tank and measurements made on pulses received before the first reflection reaches the receiver.

U. S. No. 2,453,502. G. L. Dimmick. Iss. 11/9/48. App. 5/11/44. Assign. Radio Corp. of America.

Sound-To-Image Transducing System. A system for ascertaining the nature of an object submerged in water by projecting toward it a beam of supersonic waves, impressing the reflected waves on a mosaic, each of which converts received waves into light energy and forming an optical image of the light.

U. S. No. 2,455, 389. W. Soller. Iss. 12/ 7/48. App. 2/14/44. Assign. one half to William H. Woodin, Jr.

Method and Apparatus for Separating Audio Frequencies. An apparatus for obtaining a diffraction spectrum of a complex wave in which a transmitter puts the wave into a medium containing spaced rods forming a concave grating and the diffracted frequencies are focused on a series of receivers.

* Abstracts by O. F. Ritzmann, Gulf Oil Corporation

U. S. No. 2,456,706. C. B. Horsley. Iss. 12/21/48. App. 2/2/46. Assign. Ultrasonic Corp.

Acoustic Chamber. A chamber for treating fluids with supersonic waves having the shape of a toroid with an axial inlet for the sound and a conical projection opposite the inlet to reflect the sound into the chamber.

U. S. No. 2,457, 527. E. Bruce. Iss. 12/28/48. App. 10/2/42. Assign. Bell Telephone Laboratories, Inc.

Acoustic Device. A microphone and annular sound-shield assembly in which a directional band-pass frequency characteristic is attained by the use of zonal diffraction and interference.

16—AIRPLANE FLIGHT INSTRUMENTS

U. S. No. Re. 23,042 (Orig. No. 2,406,719) R. H. Upson. Iss. 10/5/48. App. 12/7/43, 8/27/46 and 8/25/47.

Stall Warning Device. An airplane angle-of-attack indicator having a tube open at the leading edge of the wing and connected to the upper part of a capsule with a weighted slack diaphragm which is drawn against electric contacts when a negative pressure develops at the leading edge.

U. S. No. 2,452,621. J. Weissenbach. Iss. 11/2/48. App. 3/29/46.

Flight Operation Indicator. A flight operation guide for use with the air-speed indicator and which may be set for airplane gross weight and indicates safe take-off speed, maximum endurance speed and normal final approach speed.

U. S. No. 2,452,682. W. W. Remy. Iss. 11/2/48. App. 3/23/45.

Reflector Drift Indicator Apparatus for Boats and Aircraft. A drift indicator having an objective mirror mounted at the top of the airplane cabin and an eye-piece mirror at the bottom of the cabin window, the objective mirror having a vertical line and adjustable about a vertical axis with a scale.

U. S. No. 2,453,169. R. H. Varian. Iss. 11/9/48. App. 4/10/43. Assign. The Sperry Corp.

Radio Ground-Clearance Indicator. A radio ground-clearance indicator in which the wave is frequency modulated at a low rate and the reflected signal combined with a direct signal to produce amplitude-modulated pulses whose ratio is measured.

U. S. No. 2,453,607. M. C. Wardle and D. J. Howard. Iss. 11/9/48. App. 6/6/44. Assign. Curtiss-Wright Corp.

Center of Gravity Location Indicator. A device for indicating the center of gravity of an airplane having electrical resistance strain gauges on the landing gear struts connected to a Wheatstone bridge indicating circuit.

U. S. No. 2,454,007. H. L. Reilly, F. H. Scrimshaw and A. G. Bone. Iss. 11/16/48. App. 5/26/44 and 5/24/45. Assign. Henry Hughes and Son Ltd.

Navigational Instrument. An air-speed indicator in which air pressure from a fan is balanced against a pitot head and the fan speed indicated, the fan blades being made to have an increasing radius with speed so as to compensate for a compressibility error.

U. S. No. 2,454,587. G. H. Arnold. Iss. 11/23/48. App. 4/12/46.

Stall Indicating Warning Signal for Airplanes. A stall indicator having a tube extending above the upper surface of the wing so as to be outside the boundary layer of air over the wing during normal flight but within the boundary layer when approaching a stall and connected to a pressure actuated switch in a signal circuit.

U. S. No. 2,454,630. E. P. Buckthal. Iss. 11/23/48. App. 1/8/45. Assign. United Air Lines, Inc.

Method and Apparatus for Indicating Potential Gradients. A device for indicating the ambient potential gradient surrounding an airplane having probes on the wing tips and also front and rear, each pair being connected through an amplifier to one of a pair of crossed-pointer indicating meters.

U. S. No. 2,455,639. E. I. Anderson. Iss. 12/7/48. App. 10/26/43. Assign. Radio Corp. of America.

Ground Speed Indicator Utilizing Doppler Effect. A radio pulse-echo ground-speed indicator in which pulses are radiated fore and aft and the ground-reflected pulses applied to separate detectors, heterodyned to a lower frequency by a single oscillator and mixed to give a beat-frequency signal.

U. S. No. 2,455,693. W. R. Mercer. Iss. 12/7/48. App. 7/26/45. Assign. Radio Corp. of America.

Distance Determining System. A frequency-modulated radio altimeter in which the frequency-modulation band width is controlled so as to vary with distance by applying the distance counter meter to the anode supply of the modulating oscillator.

U. S. No. 2,455,939. F. W. Meredith. Iss. 12/14/48. App. 7/27/42 and 9/27/43. Assign. S. Smith & Sons (England) Ltd.

Device for Detecting Turn or Measuring Rate of Turn. A rate-of-turn indicator having an armature oscillating between magnet pole pieces in a plane normal to the axis of turn, the pole pieces having coils which through a feedback system oppose a change in the direction of oscillation, and the coil current indicated.

U. S. No. 2,457,287. C. H. Townes. Iss. 12/28/48. App. 7/7/44. Assign. Bell Telephone Laboratories, Inc.

Air-Speed Indicating System. An electrical system for reproducing the indication of an air-speed indicator through a computing device which makes corrections for altitude and temperature.

48—CASING PERFORATOR

U. S. No. 2,456,977. I. J. McCullough. Iss. 12/21/48. App. 11/1/41 Assign. McCullough Tool Co.

Well Casing Perforating Gun and Cartridge. A perforating gun cartridge having its powder chamber behind the bullet and surrounding the gun barrel and a detonator at the back of the chamber fired by deflection of a diaphragm by a firing charge.

68—COMPUTING DEVICES

U. S. No. 2,454,549. G. W. Brown and E. A. Goldberg. Iss. 11/23/48. App. 8/16/46. Assign. Radio Corp. of America.

Electronic Equation Solver. An electronic simultaneous equation solver having a-c signals adjusted to the constant terms applied to amplifiers with voltage feedback from output dividers set proportional to the coefficients of the unknown terms.

U. S. No. 2,455,974. G. W. Brown. Iss. 12/14/48. App. 11/15/46. Assign. Radio Corp. of America.

Automatic Solution of Linear Simultaneous Equations. An electronic simultaneous equation solver in which universal stability is attained by producing a-c signals representing the terms of the equations and the signals modified analogous to operating on the unknowns with a coefficient matrix and then with a transposed coefficient matrix.

80—CORE BARREL

U. S. No. 2,456,331. B. W. Sewell. Iss. 12/14/48. App. 5/2/44. Assign. Standard Oil Development Co.

Core Barrel. A wire-line operated side wall core barrel using an attachment on the lower end of the

drill stem which deflects the core barrel against the formation, the pressure core barrel having a swivel-mounted side wall core receiver.

92—DRILL

U. S. No. 2,451,223. H. C. Johansen. Iss. 10/12/48. App. 4/7/44. Assign. Joy Manufacturing Co.

Drilling Apparatus. A truck-mounted portable drill in which the rotary table is mounted on a pivoted arm so that it can be lowered for drilling and raised in moving, the table being driven through universal joints and a telescoping splined joint.

U. S. No. 2,453,204. R. H. Dobbs. Iss. 11/9/48. App. 10/24/46.

Earth Boring Machine. A portable post-hole auger mounted on a tractor and driven by a power take-off.

124—ELECTRICAL PROSPECTING

U. S. No, 2,454,911. D. H. Clewell. Iss. 11/30/48. App. 8/12/44. Assign. Socony-Vacuum Oil Co., Inc.

Geological Exploration System. A four-electrode commutated d-c electrical prospecting system in which one potential electrode is between the current electrodes and the other potential electrode is outside but on the same equipotential surface, the frequency being varied and changes in potential difference due to reflections from underground layers being observed.

128—ELECTROMAGNETIC LOGGING

U. S. No. 2,455,940. M. Muskat and N. D. Coggeshall. Iss. 12/14/48. App. 11/28/44. Assign. Gulf Research & Development Co.

Method of Geophysical Exploration by Microwaves. A method of well logging in which the microwave transmission characteristic of a section of the hole is measured.

U. S. No. 2,455,941. M. Muskrat and N. D. Coggeshall. Iss. 12/14/48. App. 12/13/44. Assign. Gulf Research & Development Co.

Geophysical Prospecting in Boreholes by Microwaves. A method of well logging in which microwaves are reflected at oblique incidence from a portion of the borehole wall and the reflected energy measured.

U. S. No. 2,455,942. N. D. Coggeshall and M. Muskat. Iss. 12/14/48. App. 12/13/44. Assign. Gulf Research & Development Co.

Geophysical Exploration of Boreholes By Microwaves. A method of well logging in which microwaves are allowed to impinge on a portion of the borehole wall at normal incidence and the energy absorption measured.

140—FLAW DETECTOR

U. S. No. 2,456,012. M. Muskat and N. D. Coggeshall. Iss. 12/14/48. App. 12/21/44. Assign. Gulf Research & Development Co.

Method of and Apparatus for Measuring the Electrical Properties and Surface Characteristics of Materials. A method for testing the outer surface of pipe for cracks and flaws by using it as the central conductor of a tubular microwave conducting system and measuring the transmission characteristic.

U. S. No. 2,457,695. C. L. Liskow. Iss. 12/28/48. App. 9/24/45. Assign. Sylvania Electric Products, Inc.

Ultra High-Frequency Apparatus for Inspecting of Sheet and Other Materials. Apparatus for detecting conducting inclusions in sheets of insulating materials by passing the sheet through a slot in a waveguide and observing the attentuation of microwave energy.

144—FLOW LOGGING

U. S. No. 2,453,456. R. G. Piety. Iss. 11/9/48. App. 3/7/45. Assign. Phillips Petroleum Co.

Instrument for Measuring Water Flow in Wells. An apparatus for measuring the distribution of water in an input well and having a container which discharges radioactive material into the water and a series of Geiger counters suspended below it which detect the arrival of the radioactive material at various levels.

148—FLOWMETER

U. S. No. 2,451,425. A. F. Allwein. Iss. 10/12/48. App. 12/18/46. Assign. The Brown Instrument Co.

Flowmeter. A flowmeter having a manometer connected across an orifice, the manometer being mounted on a balance arm so that movement of the manometer liquid changes the balance which is restored by a pneumatic system in which the pressure is indicated and is proportional to the flow.

U. S. No. 2,453,376. F. H. Lagasse. Iss. 11/9/48. App. 11/21/44.

Means for Measuring the Velocity and Volume of Fluids. A flowmeter having a V-shaped flapper pivoted about its apex in a rectangular flow-pipe, oscillations of the flapper being recorded by a photoelectric counter.

U. S. No. 2,457,297. W. F. Aller. Iss. 12/28/48. App. 11/10/44. Assign. The Sheffield Corp.

Fluid Meter. An air-flow meter for a pneumatic gauging device having a metal float which is lifted in a tapered tube and a metal spring-bumper stop at the top of the tube to prevent sticking of the float and remove electrostatic charge.

152—FLUORESCENCE LOGGING

U. S. No. 2,451,883. R. M. Squires. Iss. 10/19/48. App. 10/25/45. Assign. Socony-Vacuum Oil Co., Inc.

Geophysical Prospecting. A method of prospecting by measuring the fluorescence of soil samples, the sample being placed in a container with holes in the bottom through which a petroleum solvent enters to leach out the petroliferous material and evaporate at the top thus concentrating the fluorescent material at the top surface of the sample.

U. S. No. 2,451,885. N. P. Stevens and R. M. Squires. Iss. 10/19/48. App. 1/11/46. Assign. Socony-Vacuum Oil Co., Inc.

Geochemical Prospecting. A method of prospecting by measuring the fluorescence of soil samples, the sample being placed in a perforated container and covered by a layer of non-fluorescing granular inert material and a petroleum solvent allowed to enter the sample from below to leach out the petroliferous material and evaporate from the top layer thus concentrating the fluorescent material in the inert material.

168—GAS ANALYSIS

U. S. No. 2,457,67[illegible]. W. D. Hershberger. Iss. 12/28/48. App. 11/1/45. Assign. Radio Corp. of America.

Microwave Gas Analysis. A gas analysis apparatus in which the gas is circulated through a tuned cavity resonator and the energy loss compared with that of a pair of tuned standard resonators.

172—GEOCHEMICAL PROSPECTING

U. S. No. 2,451,883. R. M. Squires. Iss. 10/19/48. App. 10/25/45. Assign. Socony-Vacuum Oil Co., Inc.

Geophysical Prospecting. A method of prospecting by measuring the fluorescence of soil samples,

the sample being placed in a container with holes in the bottom through which a petroleum solvent enters to leach out the petroliferous material and evaporate at the top thus concentrating the fluorescent material at the top surface of the sample.

U. S. No. 2,451,885. N. P. Stevens and R. M. Squires. Iss. 10/19/48. App. 1/11/46. Assign. Socony-Vacuum Oil Co., Inc.

Geochemical Prospecting. A method of prospecting by measuring the fluorescence of soil samples, the sample being placed in a perforated container and covered by a layer of non-fluorescing granular inert material and a petroleum solvent allowed to enter the sample from below to leach out the petroliferous material and evaporate from the top layer thus concentrating the fluorescent material in the inert material.

188—HYGROMETER

U. S. No. 2,454,320. J. Hornbostel. Iss. 11/23/48. App. 5/15/43. Assign. Thomas A. Edison, Inc.

Hygrometer and Switch for Radiosondes. A temperature-compensated hair hygrometer for a chronometric radiosonde.

U. S. No. 2,454,584. P. W. Zingaro. Iss. 11/23/48. App. 10/2/44. Assign. Square D Co.

Hygrometer. An electric hygrometer having non-polarizing electrodes on the surface of an insulator coated with a hydroxide of potassium, sodium or lithium so that on electrolysis the hydroxide will be reformed by action of water.

200—LEVEL INDICATORS

U. S. No. 2,452,156. D. S. Schover. Iss. 10/26/48. App. 9/24/45. Assign. U.S.A.

Float Position Indicator. A level indicator in which a small metallic float moves inside a solenoid wound so that the number of turns per unit length increases from one end to the other, the solenoid being excited by high-frequency ac and the eddy-current loss indicated.

U. S. No. 2,456,233. A. Wolf. Iss. 12/14/48. App. 8/26/44. Assign. The Texas Co.

Liquid Level Measurement and Control. A liquid level gauge having a radioactive material on a float and a radioactivity detector outside the tank for detecting the point of maximum intensity.

U. S. No. 2,456,617. L. W. Burch. Iss. 12/21/48. App. 7/30/4,3.

Liquid Level Indicator. A liquid level gauge for a tank having a vertical resistor which is heated by a battery and with variation in current due to cooling effect of the liquid indicated.

208—LOGGING WHILE DRILLING

U. S. No. 2,452,515. L. F. Athy. Iss. 10/26/48. App. 12/13/4,3. Assign. Continental Oil Co.

Method of Making Geophysical Explorations. A method of well logging while drilling in which the vibrations set up by the drill are picked up by a detector either set on the ground or suspended in air and recorded.

224—MAGNETIC RECORDER

U. S. No. 2,456,767. M. Camras. Iss. 12/21/48. App. 11/29/45. Assign. Armour Research Foundation of Illinois Institute of Technology.

Combination of Magnetic Transducing and Erasing Heads. A combination recording and erasing head for a magnetic wire recorder using a single core with a T-shaped center leg and straight legs on each side of the T, one window being used for the erasing coil and the other for the recording and high-frequency coils.

U. S. No. 2,457,699. R. A. Marsen. Iss. 12/28/48. App. 3/29/45. Assign. Lear, Inc.

Magnetic Recorder with Friction Drive Device Incorporated Within the Magazine. A magnetic recorder having spring-pressed friction wheels which bear on the outer turn of tape on the reels and run at a controlled speed.

228—MAGNETIC TESTING

U. S. No. 2,455,874. A. J. Newman. Iss. 12/7/48. App. 4/7/44. Assign. Curtiss-Wright Corp.

Machine for Testing and Marking Parts Magnetically. A magnetic testing machine for small steel parts which applies a magnetically sensitive film to the part, drops it into a current-carrying solenoid and then turns the current off and drops the parts to an inspection station.

232—MAGNETOMETER

U. S. No. 2,451,819. A. Frosch. Iss. 10/19/48. App. 4/12/44. Assign. Standard Oil Development Co.

Induction Magnetometer. A magnetometer in which a metal element is mechanically oscillated inside a stationary coil connected to an a-c detector, the entire device being in the field of a pair of Helmholtz coils whose current is adjusted so that a minimum ac is detected.

236—MASS SPECTROMETRY

U. S. No. 2,450,462. H. W. Washburn. Iss. 10/5/48. App. 11/4/43. Assign. Consolidated Engineering Corp.

Mass Spectrometry. A mass spectrometer in which gas from the electron source is prevented from reaching the ionization chamber by a baffle and the pump is connected so that gas is drawn from the ionization chamber through the analyzer and through the electron producing chamber.

U. S. No. 2,456,426. A. O. C. Nier and E. P. Ney. Iss. 12/14/48. App. 8/8/44. Assign. U.S.A.

Mass Spectrometer System. A system for measuring the ratio of two ion currents in a mass spectrometer by reversing one of the currents with a feedback amplifier, applying it across a potentiometer and balancing the other current against a portion of the potentiometer.

U. S. No. 2,457,162. R. V. Langmuir. Iss. 12/28/48. App. 4/20/43. Assign. Consolidated Engineering Corp.

Mass Spectrometry. A mass spectrometer having a pair of plates in the ionizing region to which an a-c voltage is applied so as to obtain a pulsating ion beam which is collected and the resulting ion current amplified by an a-c amplifier.

U. S. No. 2,457,530. N. D. Coggeshall and N. F. Kerr. Iss. 12/28/48. App. 8/6/46. Assign. Gulf Research & Development Co.

Electron Gun for Mass Spectrometers. An electron gun which obtains electrons from a photoelectric multiplier tube which is automatically controlled by having the final electron current control the intensity of the lamp.

240—MECHANICAL LOGGING

U. S. No. 2,452,515. L. F. Athy. Iss. 10/26/48. App. 12/13/43. Assign. Continental Oil Co.

Method of Making Geophysical Explorations. A method of well logging while drilling in which the vibrations set up by the drill are picked up by a detector either set on the ground or suspended in air and recorded.

276—PERMEABILITY TESTING

U. S. No. 2,451,797. A. Blanchard. Iss. 10/19/48. App. 2/17/45. Assign. Schlumberger Well Surveying Corp.

Apparatus for Producing Pressure Pulses in Boreholes. A dumbbell-type oscillator which may be

lowered into a well and having two casings connected by a resilient tube, the system being oscillated at its resonant frequency through an electromechanical feedback.

288—PRESSURE GAUGE

U. S. No. 2,450,625. J. W. Beecher. Iss. 10/5/48. App. 11/30/44. Assign. The Bristol Co.

Fluid-Pressure-Responsive Element. A Bourdon gauge in which large cross-sectional area and low volume are attained by having inside the main tube a loose hollow elliptical tube which is connected to the atmosphere.

U. S. No. 2,454,264. W. H. Stigter. Iss. 11/16/48. App. 8/31/40 and 1/19/43. Assign. Hartford National Bank and Trust Co.

Piezoelectric Device for Converting Pressure Variations into Potential Variations. A piezoelectric pressure indicator in which the crystals are held under a preliminary pressure by a dished spring washer between the crystals and the housing.

U. S. No. 2,455,021. F. Rieber. Iss. 11/30/48. App. 1/29/44. Assign. Interval Instruments, Inc.

Pressure Meter. An electrical pressure gauge in which a Bourdon tube tensions a wire in a magnetic field and kept in sustained vibration by a feedback circuit whose frequency is indicated and also having a bimetallic temperature compensator between the Bourdon tube and the wire.

U. S. No. 2,455,883. L. D. Statham. Iss. 12/7/48. App. 4/10/45. Assign. Curtiss-Wright Corp.

Electric Pressure Strain Gauge. A pressure gauge having a diaphragm whose deflection is transmitted to a filament-type strain gauge connected in a bridge circuit.

304—RADIOACTIVITY LOGGING

U. S. No. 2,451,472. N. D. Coggeshall. Iss. 10/19/48. App. 4/16/45. Assign. Gulf Research & Development Co.

Method of Cementing Wells. A method of cementing in which a radioactive material is added to the drilling mud so that any mud not displaced by the cement may be detected by a radioactivity log and corrected by squeeze cementing.

U. S. No. 2,451,520. A. J. Teplitz. Iss. 10/19/48. App. 5/29/45. Assign. Gulf Research & Development Co.

Method of Completing Wells. A method of locating channeling in a well after casing and cement has been perforated by forcing a radioactive drilling mud into the producing formation and running a radioactivity log, then allowing the well to produce a short time and again running a radioactivity log and determining the source of water or gas by comparing the two logs and squeeze cementing to shut off the channels.

U. S. No. 2,453,318. R. E. Hartline. Iss. 11/9/48. App. 12/17/45. Assign. Stanolind Oil and Gas Co.

Radioactivity Logging Device. A radioactivity logging apparatus in which the air is circulated by a fan through filters and drying agents and discharged near the electrometer resistor so as to avoid the effects of moisture on the resistor.

308—RADIOACTIVITY MEASUREMENTS

U. S. No. 2,452,524. H. Metten. Iss. 10/26/48. App. 1/2/48. Assign. Sylvania Electric Products, Inc.

Protective Grid for Geiger-Mueller Tubes. A beta ray counter having a grid connected to the cathode near the anode and close to the thin metal window to protect the latter from damage by arcing.

U. S. No. 2,456,233. A. Wolf. Iss. 12/14/48. App. 8/26/44. Assign. The Texas Co.

Liquid Level Measurement and Control. A liquid level gauge having a radioactive material on a float and a radioactivity detector outside the tank for detecting the point of maximum intensity.

316—RADIO RANGING

U. S. No. 2,450,945. T. T. Eaton. Iss. 10/12/48. App. 9/13/41. Assign. Radio Corp. of America.

Pulse-Echo Motion Detector. A radio pulse-echo system for determining motion of a reflecting object toward or away from the apparatus in which the rate of coincidence of source pulses and reflected pulses is indicated on a frequency meter calibrated in velocity.

U. S. No. 2,450,946. J. Evans. Iss. 10/12/48. App. 4/25/44. Assign. Radio Corp. of America.

Pulse-Echo Radio Velocity Indicator. A radio pulse-echo system in which the reflection pulses are centered on the time axis of a c-r tube and the required amount of centering control indicated.

U. S. No. 2,451,000. R. M. Smith. Iss. 10/12/48. App. 11/30/40. Assign. Radio Corp. of America.

Repeater Indicator for Pulse-Echo Distance Measuring Devices. A remote repeater for a radar system in which an image of the radar screen is focussed onto a mosaic and scanned at a low frequency and the minimum reflection distance indicated on a meter.

U. S. No. 2,451,141. I. Wolff. Iss. 10/12/48. App. 10/29/38. Assign. Radio Corp. of America.

Object Detecting Device. A radio pulse-echo system using a carrier which is frequency modulated by discrete pulses and the reflected signal combined with the transmitted signal.

U. S. No. 2,452,546. H. G. Busignies and J. L. Allison. Iss. 11/2/48. App. 6/20/45. Assign. Federa Telephone and Radio Corp.

Direction Finder. A radio direction finder in which the signal is picked up by a main antenna and alternately reradiated at adjustable phase by two secondary antennas located one on each side of the main antenna and whose tuning is controlled by a local injection signal.

U. S. No. 2,452,564. M. K. Goldstein. Iss. 11/2/48. App. 5/15/45.

Direction Finder. An automatic radio direction finder in which the position of the movable coil of the goniometer is controlled by a two-phase servo-motor which also drives the indicator.

U. S. No. 2,452,675. J. H. Newitt. Iss. 11/2/48. App. 5/4/46. Assign. Federal Telephone and Radio Corp.

Direction Finding System. A radio direction finder using two loops, each feeding a separate pair of balanced modulators which are also excited in quadrature at low frequency and indicating on a c-r tube.

U. S. No. 2,456,666. C. S. Agate and A. H. Cooper. Iss. 12/21/48. App. 9/25/41 and 11/22/43 Assign. Electric & Musical Industries Ltd.

Radio Direction Finding System. A radio direction finder using two rotating receiving antennas and producing an indication on a c-r tube screen when their signals are equal in intensity.

324—RECORDER

U. S. No. 2,451,464. A. E. Anderson,. Iss. 10/19/48. App. 9/8/43 and 9/15/45. Assign. Submarine Signal Co.

Recorder. An echo sounding recorder in which a stylus moves across the record paper and an indication made when a reflection is received and also having a continuous signal which may be applied to the stylus to mark a fix-line across the paper when desired.

U. S. No. 2,457,214. H. G. Doll and G. K. Miller. Iss. 12/28/48. App. 7/21/42. Assign. Schlumberger Well Surveying Corp.

Recording Device. An avc system for a recording device in which the signal is fed into two rectifiers whose outputs are in opposition but one of which operates only when the input signal exceeds a predetermined level.

344—SEISMOGRAPH AMPLIFIER

U. S. No. 2,456,401. R. P. Gilmore. Iss. 12/14/48. App. 9/24/45. Assign. Shell Development Co.

Interference Eliminator for Seismic Recording Systems. A system for eliminating 60-cycle pickup by picking up the stray signal and applying it to quadrature coils through a phase-splitting network to obtain a rotating field and applying the signal from a properly oriented secondary coil to each amplifier to neutralize its pickup signal.

372—SEISMOGRAPH VOLUME CONTROL

U. S. No. 2,454,169. H. E. Haynes. Iss. 11/16/48. App. 12/26/46. Assign. Radio Corp. of America.

Gain Control System Responsive to an Average Value. An avc system for a sound track reproducing system in which the average signal voltage across an R-C circuit controls the power supply for the dynode voltages of an electron multiplier phototube.

U. S. No. 2,457,214. H. G. Doll and G. K. Miller. Iss. 12/28/48. App. 7/21/42. Assign. Schlumberger Well Surveying Corp.

Recording Device. An avc system for a recording device in which the signal is fed into two rectifiers whose outputs are in opposition but one of which operates only when the input signal exceeds a predetermined level.

U. S. No. 2,457,712. H. F. Olson and J. Preston. Iss. 12/28/48. App. 9/21/45. Assign. Radio Corp. of America.

Method and Apparatus for Noise Control of Reproduced Sound. A system for automatically adjusting the signal-to-noise ratio in an amplifying system prior to operation by having the noise signal drive a torque motor which rotates a spring-biased volume control.

392—SIDE WALL SAMPLER

U. S. No. 2,456,331. B. W. Sewell. Iss. 12/14/48. App. 5/2/44. Assign. Standard Oil Development Co.

Core Barrel. A wire-line-operated side wall core barrel using an attachment on the lower end of the drill stem which deflects the core barrel against the formation, the pressure core barrel having a swivel-mounted side-wall core receiver.

400—SOIL GAS SAMPLING

U. S. No. 2,457,707. W. K. Neuman and H. M. Slosberg. Iss. 12/28/48. App. 9/9/44. Assign. Continental Can Co., Inc.

Gas Sampling Device. A device for removing gas from a tin can and having a sealed grip around the outside of the can and a sealed perforated plunger which is pushed through the top of the can and through which the gas may be withdrawn.

412—SPECIFIC GRAVITY MEASUREMENTS

U. S. No. 2,451,036. J. R. Martin and F. B. Burrell. Iss. 10/12/48. App. 9/30/44. Assign. Standard Oil Development Co.

Specific Gravity Recorder. A device for continuously recording the specific-gravity of flowing

liquid having a submerged float in the liquid connected through a linkage submerged in an intermediate sealing liquid to a float on mercury, motion of the linkage being mechanically transmitted to the recording pen.

416—SPECTROGRAPH

U. S. No. 2,453,164. P. F. Swings. Iss. 11/9/48. App. 5/19/45. Assign. Lane-Wells Co.

Plural Grating Spectrograph. A spectrograph for both the visible and ultra-violet regions having two concave gratings with the same radius of curvature and different grating space and illuminated by the same slit.

428—STRAIN GAUGE

U. S. No. 2,452,860. F. C. Mostertz. Iss. 11/2/48. App. 6/12/47. Assign. F. F. Metzger and Son.

Extensometer or Strain Gauge. A mechanical strain gauge using lever magnification and a dial micrometer indicator.

U. S. No. 2,453,549. L. D. Statham. Iss. 11/9/48. App. 7/14/47. Assign. Statham Laboratories, Inc.

Electric Strain Gauge. A filament-type strain gauge in which the wires are not bonded to a backing plate and are carried on pins attached to a bell crank which multiplies the force.

U. S. No. 2,453,550. L. D. Statham. Iss. 11/9/48. App. 7/14/47. Assign. Statham Laboratories, Inc.

Bar-Type High-Range Gauge. A draw-bar dynamometer whose bar has a rectangular opening in which there is mounted a strain sensitive filament.

U. S. No. 2,453,551. L. D. Statham. Iss. 11/9/48. App. 7/31/47. Assign. Statham Laboratories, Inc.

Ring-Type Resistance Strain Gauge Dynamometer. A draw-bar dynamometer having a ring stressed at diametrically opposite points with a strain sensitive filament across the perpendicular diameter.

U. S. No. 2,453,601. L. D. Statham, C. J. Baker and K. D. Swartzel. Iss. 11/9/48. App. 9/21/44. Assign. Curtiss-Wright Corp.

Electric Strain Gauge. A filament-type strain gauge having a base with insulated pins between which the filament is wound.

U. S. No. 2,455,285. F. F. Versaw. Iss. 11/30/48. App. 9/13/45. Assign. Gulf Research & Development Co.

Strain Gauge. A strain gauge in which the strain varies the distance between an air discharge nozzle and an opposed target, the nozzle being in series with a fixed flow resistance and the pressure between them indicated.

U. S. No. 2,457,616. W. D. Van Dyke and P. S. Dennis. Iss. 12/28/48. App. 7/16/46. Assign. Douglas Aircraft Co., Inc.

Metal Foil-Type Strain Gauge and Method of Making Same. A method of making surface-type electric strain gauges by insulating a thin strain-sensitive strip on both sides, punching rows of longitudinal rectangular holes and then cutting off transverse sections which have the shape of a zig-zag conductor which may be cemented to the test surface.

436—SUBMARINE SIGNALING

U. S. No. 2,450,412. H. Benioff. Iss. 10/5/48. App. 11/20/42. Assign. Submarine Signal Co.

Device for Transmitting and Receiving Compressional Energy. A magnetostriction hydrophone whose front plate has outwardly and inwardly projecting blocks which form radiating vibrators with

the plate at the nodal plane, the driving elements being mounted on the inward projection and the back plate having inward projecting rods which support the elements when an excessive shock is received.

U. S. No. 2,451,967. F. Massa. Iss. 10/19/48. App. 6/2/44 and 7/28/47. Assign. The Brush Development Co.

Vibrational Energy Transmitter or Receiver. A directional hydrophone whose radiating piston is divided into zones which are driven at different specified relative amplitudes so as to attain optimum relation between energy radiated in the main lobe relative to energy in side lobes.

U. S. No. 2,451,968. A. Murdoch, Jr. Iss. 10/19/48. App. 1/3/40. Assign. Radio Corp. of America.

Magnetostrictive Electroacoustic Transducer. A submarine signaling transmitter having a large radiating surface and a triangular array of magnetostrictive elements arranged so that the spheres of influence of adjacent elements border each other leaving a minimum of uninfluenced radiating surface.

U. S. No. 2,452,068. R. E. Peterson. Iss. 10/26/48. App. 1/23/43. Assign. Submarine Signal Co.

Sound Pickup Device. A hydrophone whose case is filled with fluid and having a sonic lens which focuses the energy on a series of piezoelectric units backed up by a heavy block.

U. S. No. 2,452,085. E. E. Turner, Jr. Iss. 10/26/48. App. 8/6/42. Assign. Submarine Signal Co.

Means for the Interchange of Electrical and Acoustical Energy. A submarine signaling transducer having a cylindrical housing containing a stack of magnetostrictive laminations having the shape of a cross whose ends are in contact with the housing.

U. S. No. 2,452,086. E. E. Turner, Jr. Iss. 10/26/48. App. 3/10/45. Assign. Submarine Signal Co.

Sound Producer and Receiver. A submarine signaling transducer whose piston is flat on the radiating face and has annular concentric sections on the back face having the form of cycloidal arches driven at the vertices of the arches.

U. S. No. 2,452,570. B. R. Hubbard. Iss. 11/2/48. App. 5/5/33. Assign. Submarine Signal Co.

Compressional Wave Transmitting and Receiving Device. A piezoelectric submarine-signaling transceiver having a series of crystals which are supported by side electrodes with one end against a backing plate and the other end acting through a fluid to a diaphragm.

U. S. No. 2,452,571. I. C. Clement. Iss. 11/2/48. App. 6/14/33. Assign. Submarine Signal Co.

Sound Signaling Apparatus. A piezoelectric submarine-signaling transceiver having a series of compressional crystals supported on one side by glyptal mountings on a backing plate and with the other side acting against a thick rubber diaphragm.

U. S. No. 2,453,502. G. L. Dimmick. Iss. 11/9/48. App. 5/11/44. Assign. Radio Corp. of America.

Sound-To-Image Transducing System. A system for ascertaining the nature of an object submerged in water by projecting toward it a beam of supersonic waves, impressing the reflected waves on a mosaic each element of which converts received waves into light energy and forming an optical image of the light.

U. S. No. 2,455,475. S. D. Eilenberger. Iss. 12/7/48. App. 9/15/43. Assign. Chicago Coin Machine Co.

Method of Ultrasonic Pulse Signaling. A submarine signaling system in which the message is recorded on a magnetic tape, then transmitted as an ultrasonic pulse by running the tape at high speed and the process inverted at the receiving end.

U. S. No. 2,456,294. F. Massa. Iss. 12/14/48. App. 5/15/46. Assign. The Brush Development Co.

Underwater Sound Transmitter or Receiver. A fluid-filled multi-element piezoelectric hydrophone or projector in which all but the operating pair of faces of the crystals are covered by a compressible material so as to decouple non-operative faces from the liquid medium.

U. S. No. 2,456,598. O. H. Schuck. Iss. 12/14/48. App. 8/31/44. Assign. U.S.A.

Method and Apparatus for Monitoring Underwater Echo Range and Bearing Systems. A frequency monitoring apparatus for a submarine signaling system which measures energy received so that the frequency may be adjusted for maximum projector output and the receiver adjusted to the same frequency.

448—TENSION INDICATOR

U. S. No. 2,452,302. H. Hitchen. Iss. 10/26/48. App. 7/16/43 and 11/13/44. Assign. British Ropes Ltd.

Cable Tensiometer. A cable tensiometer in which the cable is deflected against the same side of each of three pulleys not in the same line by two outer pulleys and the deflection mechanically recorded by a stylus.

U. S. No. 2,453,550. L. D. Statham. Iss. 11/9/48. App. 7/14/47. Assign. Statham Laboratories, Inc

Bar-Type High-Range Gauge. A draw-bar dynamometer whose bar has a rectangular opening in which there is mounted a strain-sensitive filament.

U. S. No. 2,453,551. L. D. Statham. Iss. 11/9/48. App. 7/31/47. Assign. Statham Laboratories, Inc.

Ring-Type Resistance Strain Gauge Dynamometer. A draw-bar dynamometer having a ring stressed at diametrically opposite points with a strain-sensitive filament across the perpendicular diameter.

460—THERMOMETER

U. S. No. 2,454,552. R. W. Cobean. Iss. 11/23/48. App. 4/8/44. Assign. General Electric Co.

Temperature Responsive Device. A bimetallic thermostat strip wound edgewise into a helix but with the strip making an acute angle with the axis of the helix so as to obtain a nonlinear angular deflection with temperature changes.

U. S. No. 2,456,801. W. A. Tolson. Iss. 12/21/48. App. 2/14/44. Assign. Radio Corp. of America.

Optical Heat Detection System. Apparatus for forming a visible image of a heat image by focusing the heat on a mosaic of heat-sensitive cells which form compression waves and deflect a very thin aluminum-coated plastic diaphragm which reflects light from a multiaperatured light source corresponding to the mosaic through a similarly aperatured plate onto a viewing screen.

484—TRANSDUCER

U. S. No. 2,450,412. H. Beinoff. Iss. 10/5/48. App. 11/20/42. Assign. Submarine Signal Co.

Device for Transmitting and Receiving Compressional Energy. A magnetostriction hydrophone whose front plate has outwardly and inwardly projecting blocks which form radiating vibrators with the plate at the nodal plane, the driving elements being mounted on the inward projection and the backplate having inward projecting rods which support the elements when an excessive shock is received.

U. S. No. 2,451,967. F. Massa. Iss. 10/19/48. App. 6/2/44 and 7/28/47. Assign. The Brush Development Co.

Vibrational Energy Transmitter or Receiver. A directional hydrophone whose radiating piston

is divided into zones which are driven at different specified relative amplitudes so as to attain optimum relation between energy radiated in the main lobe relative to energy in side lobes.

U. S. No. 2,451,968. A. Murdoch, Jr. Iss. 10/19/48. App. 1/3/40. Assign. Radio Corp. of America.

Magnetostrictive Electroacoustic Transducer. A submarine signaling transmitter having a large radiating surface and a triangular array of magnetostrictive elements arranged so that the spheres of influence of adjacent elements border each other leaving a minimum of uninfluenced radiating surface.

U. S. No. 2,452,068. R. E. Peterson. Iss. 10/26/48. App. 1/23/43. Assign. Submarine Signal Co.

Sound Pickup Device. A hydrophone whose case is filled with fluid and having a sonic lens which focuses the energy on a series of piezoelectric units backed up by a heavy block.

U. S. No. 2,452,085. E. E. Turner, Jr. Iss. 10/26/48. App. 8/5/42. Assign. Submarine Signal Co.

Means for the Interchange of Electrical and Acoustical Energy. A submarine signaling transducer having a cylindrical housing containing a stack of magnetostrictive laminations having the shape of a cross whose ends are in contact with the housing.

U. S. No. 2,452,086. E. E. Turner, Jr. Iss. 10/26/48. App. 3/10/45. Assign. Submarine Signal Co.

Sound Producer and Receiver. A submarine signaling transducer whose piston is flat on the radiating face and has annular concentric sections on the back face having the form of cycloidal arches driven at the vertices of the arches.

U. S. No. 2,452,570. B. R. Hubbard. Iss. 11/2/48. App. 5/5/33. Assign. Submarine Signal Co.

Compressional Wave Transmitting and Receiving Device. A piezoelectric submarine signaling transceiver having a series of crystals which are supported by side electrodes with one end against a backing plate and the other end acting through a fluid to a diaphragm.

U. S. No. 2,452,571. I. C. Clement. Iss. 11/2/48. App. 6/14/33. Assign. Submarine Signal Co.

Sound Signaling Apparatus. A piezoelectric submarine-signaling transceiver having a series of compressional crystals supported on one side by glyptal mountings on a backing plate and with the other side acting against a thick rubber diaphragm.

U. S. No. 2,452,862. J. J. Neff. Iss. 11/2/48. App. 10/19/45. Assign. Jack & Heintz Precision Industries, Inc.

Electric Gauging Head. A displacement piickup unit having three coaxial coils, two of which are fixed and the other movable with an armature, one set of coils being excited by an a-c source and the other set connected to a vacuum-tube voltmeter.

U. S. No. 2,454,425. B. B. Bauer. Iss. 11/23/48. App. 12/24/41 and 12/23/43. Assign. Shure Brothers, Inc.

Magnetic Translating Device. A magnetic pickup or speaker in which the field coil magnetic circuit is separate from the voice coil magnetic circuit, the latter being carried on the moving armature and interacting with the field only in the air gap.

U. S. No. 2,454,496. H. W. Ashton. Iss. 11/23/48. App. 4/9/47. Assign. O. W. Storey & Associates.

Transducer. A microphone or phonograph pickup in which a large space with a diaphragm is connected to a capillary electrometer so that the liquid is caused to move by vibration of the diaphragm.

U. S. No. 2,454,497. H. W. Ashton. Iss. 11/23/48. App. 8/8/47. Assign. O. W. Storey & Associates.

Electrical Apparatus. A capillary electrometer transducer in which the liquid system communicates to a chamber filled with an inert gas at high pressure to prevent the formation of bubbles in the capillaries.

U. S. No. 2,456,294. F. Massa. Iss. 12/14/48. App. 5/15/46. Assign. The Brush Development Co.

Underwater Sound Transmitter or Receiver. A fluid-filled multi-element piezoelectric hydrophone or projector in which all but the operating pair of faces of the crystals are covered by a compressible material so as to decouple nonoperative faces from the liquid medium.

U. S. No. 2,456,388. L. B. Cornwell. Iss. 12/14/48. App. 4/3/46.

Magnetic Sound Translating Head. A magnetic-type phonograph pickup for either lateral or vertical cut records and having its pole pieces and armature so arranged that the armature cannot touch the pole pieces.

U. S. No. 2,457,527. E. Bruce. Iss. 12/28/48. App. 10/2/42. Assign. Bell Telephone Laboratories, Inc.

Acoustic Device. A microphone and annular sound-shield assembly in which a directional band-pass frequency characteristic is attained by the use of zonal diffraction and interference.

496—VISCOSIMETER

U. S. No. 2,457,247. W. D. Lawshe. Iss. 12/28/48. App. 8/28/46. Assign. Monsanto Chemical Co.

Viscosimeter. A torsional viscosimeter having a motor-rotated cup surrounding a torsion disc suspended on a fine wire with a lost-motion coupling to a stiff wire so that the stiff wire operates only when the torsion is large.

500—VOLTMETER

U. S. No. 2,454,630. E. P. Buckthal. Iss. 11/23/48. App. 1/8/45. Assign. United Air Lines, Inc.

Method and Apparatus for Indicating Potential Gradients. A device for indicating the ambient potential gradient surrounding an airplane having probes on the wing tips and also front and rear, each pair being connected through an amplifier to one of a crossed pointer indicating meter.

512—WELL SHOOTING

U. S. No. 2,451,443. E. Merten. Iss. 10/12/48. App. 11/27/45. Assign. Shell Development Co.

Apparatus for Orientation. A device for determining the azimuthal orientation of a well detector or drilling tools in a well which has two undamped coaxially suspended coils through which a current may be momentarily passed to impart motion and then recording the emf induced in the coils while freely vibrating in the earth's magnetic field.

520—WELL SURVEYING

U. S. No. 2,451,443. E. Merten. Iss. 10/12/48. App. 11/27/45. Assign. Shell Development Co.

Apparatus for Orientation. A device for determining the azimuthal orientation of a well detector or drilling tools in a well which has two undamped coaxially suspended coils through which a current may be momentarily passed to impart motion and then recording the emf induced in the coils while freely vibrating in the earth's magnetic field.

ERRATUM

In the preceding issue of *Geophysics* (Vol. XIV, No. 1, January, 1949) on page 75 the patent number given as 2,466,844 should read 2,446,844.

REVIEWS

SPECIAL REVIEWS COMMITTEE

RICHARD A. GEYER, *Chairman*, Humble Oil and Refining Co., Houston.
MISS FLORENCE ROBERTSON, St. Louis University, St. Louis.
C. HEWITT DIX, California Institute of Technology, Pasadena.
MILTON B. DOBRIN, Columbia University, New York.
K. R. WEATHERBURN, Shell Exploration and Production Lab., Houston.
HENRY E. JOESTING, U. S. Geological Survey, Washington.

Developpements Modernes de La Gravimetrie by R. P. Pierre LeJay (Gauthier Villars, Paris).

This book is composed of two parts. Part One (47 pages) is titled "Modern Methods of the Measurement of Relative Gravity." Part Two (pages 51 to 226), "The Exploitation of the Results," is largely on geodetic applications.

Part One discusses the various types of gravity measuring instruments with brief descriptions of several different gravimeters. It is perhaps to be expected that the instruments described are largely European. The only American instruments mentioned are those of Truman, Hartley, and LaCoste and Romberg. Several pages are devoted to the Holweck-LeJay inverted pendulum. Some twelve pages are given to a rather complete description and mathematical analysis of the Vening-Meinesz, 3-Pendulum apparatus as used in submarines. The different instruments are treated with a moderate amount of mathematical analysis, covering, for the most part, the fundamental principles of the type rather than an analysis of a particular instrument.

Part Two has nine chapters. The first seven deal with the relations of gravity to the shape of the earth; the various theories of isostasy and the methods of calculation of corresponding gravity effects and anomalies; the different geoids and ellipsoids of reference; the deviation of the vertical, etc. Chapter VIII (48 pages) is on the relation of gravity anomalies to geology at great depth. It reproduces and reviews briefly several isostatic maps of continental proportions. There is a brief review of Bullards' gravity work on the Rift Valleys of east Africa and their probable structure. There is a critical review of the different systems of isostatic compensation and of their probable reality. The American acceptance of the Pratt-Hayford system as a physical reality is criticized. Chapter IX (7 pages) on gravity anomalies and shallower subsurface geology is disappointing as it is largely confined to the computed effects for some simple geometrical forms to emphasize the ambiguity of gravity anomalies. The book concludes with several tables for calculation of topographic and other effects for isostatic reduction.

The part of the book on gravimetric instrumentation contain little not now readily available. Part Two will be of principal interest to geodesists and specialists interested in isostasy and methods of making isostatic reductions. Those who have followed isostasy, particularly the work of Hayford and Bowie, will be interested in the discussion of the physical reality of isostasy as distinguished from the assumptions made for mathematical convenience in calculating isostatic reductions.

To the exploration geophysicist and geologist there is too much emphasis on the details of isostatic reductions and not enough on its geological significance. In this respect this work is not comparable, for instance, with Daly's "Strength and Structure of the Earth" (see review in *Geophysics*, Vol. VI, No. 1 (Jan. 1941)).

L. L. NETTLETON

"Recent Regional Gravity Surveys" by George Prior Woollard. *Trans. American Geophysical Union, 29* (1948). Pp. 727–738.

For some years Dr. Woollard has taken a leading role in the measurement and mapping of gravity values and magnetic elements in the United States. His purpose has been to study the distribution of mass within the earth's crust and interpret it in terms of observed geological features. In the early gravity surveys measurements were made slowly and tediously with cumbersome pendulum equip-

ment and then only within a precision of a few milligals. Now gravity meters, developed primarily for oil prospecting, obtain values with much higher precision in a fraction of the time previously required. Although the great majority of gravity stations have been taken by oil companies their surveys were not planned with a view to establishing a nation-wide gravity network. The large-scale gravity features of greatest interest to the geodesist and structural geologist must be removed from commercial gravity maps in order to bring out the more local anomalies associated with possible oil-bearing structures.

In this article, a progress report on current regional gravitational surveys in North America, Dr. Woollard tells how many oil companies have been cooperating effectively in the establishment of nation-wide networks in a way that does not deprive them of the competitive advantage to which they are entitled by their expenditure for the work. From a network of gravity values taken at one-fourth-mile to two-mile intervals, values picked out at eight- to ten-mile intervals are contributed to the U.S. Coast and Geodetic Survey. These make it possible to determine regional effects but they cannot be used to detect the small local anomalies which alone have economic significance.

In addition, a number of government agencies, both in the United States and Canada, and private institutions have been conducting surveys which will contribute to the nation-wide network. The U. S. C. and G. S., which has established 1,200 pendulum stations since 1896, plans to resume this activity following a wartime cessation. The U. S. Geological Survey, which has carried on a detailed offshore gravity survey in the Gulf of Mexico, plans a regional gravity survey in the mid-continent. Columbia University is also conducting regional surveys with commercial gravity meters, on land traverses in the eastern United States. Canada, Newfoundland, Alaska, and South America, as well as an extensive submarine program for measurements offshore with a Vening Meinesz pendulum. The determinations at sea have been sponsored in cooperation with the Office of Naval Research.

Such surveys differ in a number of ways from the standard gravity surveys of oil prospecting. The scale of the enterprise is usually smaller. Often it is a one-man project, where stations are located, when possible, at established benchmarks to avoid the expense of topographic surveying for elevations. Gravity meter readings must be tied to established pendulum stations where an absolute value of gravity has been measured. Corrections are different in that isostatic variations must be taken into account. Yet both types of measurement are fundamentally the same and the geodesist and tectonophysicist are indebted to the commercial geophysicists for their contributions, both in the form of data and instruments, to the ultimate establishment of an adequate nation-wide network of gravity values.

MILTON B. DOBRIN

"Reflections on the Last Twenty-Five Years of Geophysical Work in China" by S. P. Lee. *Bulletin of the Seismological Society of America, 38* (1948). Pp. 81–88.

At the time he prepared this article, the author, who is director of the geophysical laboratory of China's National Geological Survey, was in England purchasing instruments and equipment as the first step in reconstructing his country's geophysical research facilities, destroyed almost completely during eight years of Japanese occupation. Here he tells the story of the uphill struggle which geophysics has had in China ever since its introduction there a quarter of a century ago. Hampered both in peace and war by extreme shortages of properly trained personnel and funds, the few geophysical institutions all suffered repeated damage and loss of equipment throughout the long war. Even the pathetically ill-equipped laboratory set up in the interior near Chungking was continually hampered in its work by shortages of essential tools, materials, and power, as well as by the psychological interference which incessant air raids inevitably caused. The perseverance with which these disheartening obstacles were faced and the ingenuity with which they were met cannot fail to evoke admiration from the geophysicists in this country whose wartime work was fortunately not beset by such difficulties.

Chinese seismology during its first 25 years has all been directed toward the study of earthquakes, no seismic prospecting having as yet been undertaken. From 1930 until July, 1937, earthquakes were registered systematically at a number of stations and all data were published regularly in a seismolog-

ical bulletin. The Japanese invasion stopped these operations nd it was not until August, 1943, that a new seismograph could be laboriously constructed and registration could be begun again, this time at Pehpei, near Chungking. Since the war's end rehabilitation has been hindered by the economic collapse from which China is now suffering so severely.

When the government geophysical laboratory was first driven by the Japanese into the interior, highest priority was given, for obvious reasons, to geophysical prospecting. An Eötvös torsion balance was imported via Hong Kong and used to search for galena deposits and also to locate extensions of known hematite bodies. When ordered, this instrument was intended for areas where the terrain was flat, but when it arrived, only the mountains were still accessible for prospecting and the necessary corrections were too large for its readings in such country to be useful. A Schmidt magnetic balance, procured at the same time, proved more useful, although valuable magnetite deposits which it found could not be developed because of transportation difficulties. Electrical surveys for metallic ores, undertaken some time before the war, were resumed during the occupation and resulted in about fifteen reports. In addition, electric logging and gravimetric surveying were introduced at the Kansu oil field during this period.

As part of another wartime geophysical project, three magnetic expeditions surveyed most of southwest and west China with a magnetic theodolite and an earth inductor, which the National Geological Survey managed to import from Germany through the Japanese blockage. A magnetic observatory, established near Nanking in 1935, was destroyed when Nanking was bombed and those instruments rescued from it were lost in a later attack. Several years before the war, LeJay established 167 gravity stations in China during the course of a larger pendulum survey of southeast Asia and the Philippines.

"The reader may be surprised," says Lee in conclusion, "that so little has been accomplished (in 25 years)." In view of the difficulties which he so graphically points out, most readers are more likely to be surprised that anything useful has been accomplished at all. The fortitude which Chinese geophysicists displayed under these difficulties leads their colleagues on this side of the Pacific to hope strongly that conditions in their country will somehow reach the state where all their worth-while objectives can be achieved with less obstacles and suffering than heretofore.

MILTON B. DOBRIN

"Electron Microfossils" by H. M. Barton and D. J. Jones. *Science, 108* (1948). Pp. 745–746.

This paper is a preliminary progress report on some researches that should, if successful, lead to a new geophysical technique of correlation between oil wells. It describes how the electron microscope has been used to look for microfossils, smaller than those observable with an ordinary microscope, which might be distinctive enough to serve as guides to correlation. In addition, the instrument has been used to investigate whether features in the microstructure of certain rocks can be employed for the same purpose.

The technique was tested as a possible attack on the problem of identifying formations where wells penetrate thick shale sections with no petrological or usual paleontological markers. If fossils detectable only with the electron microscope exist, they might be fossilized bacteria or spores, either of which might turn out to be characteristic of time divisions within the formation in which they occur.

Samples were collected from three widely separated locations of formations covering the time range from Paleozoic to Cenozoic. Suspensions of each were examined under the electron microscope. The authors hoped to discover distinctive shapes or patterns which could be associated with specific formations. Although numerous objects were found, none were promising as markers since they were about equally prevalent in all formations studied. Most common were discoids, which might have been fossilized spores, but several rod-like and other distinctive patterns were revealed.

Although results thus far do not establish the feasibility of the electron microscope as a tool for correlation, the authors believe that the method offers possibilities and that further experimentation

is justified. They propose that a catalogue of electron microfossils be compiled from numerous well samples by independent workers using standardized techniques.

Although somewhat removed from the usual channels of geophysical activity, this research is worthy of note as an illustration of how the petroleum industry is endeavoring to enlist the aid of all the tools of modern physics to solve the problems that arise in petroleum exploration.

MILTON B. DOBRIN

"Annotated Bibliography of Papers on Geochemical Prospecting for Ores" compiled by H. E. Hawkes. *United States Department of the Interior Geological Survey Circular 28* (August, 1948), Washington, D. C.

This annotated bibliography of approximately 70 items should be particularly helpful to those geophysicists and geologists who become interested in this field. A very complete coverage of foreign periodicals is also included. It should be noted that no papers on general geochemistry are included on this list nor are there references to geochemical prospecting for petroleum which are adequately covered in the *Geophysical Abstract* series published by the U. S. Department of the Interior. In addition, references dealing primarily with analytical methods are only listed when some direct relationship to geochemical prospecting problems is also presented.

R. A. GEYER

Journal of the Chinese Geophysical Society, Vol. 1, No. 1, (1948). Published by the Chinese Geophysical Society.

The initial issue of this new periodical published in China should be of interest because the articles for the most part describe the results of various types of geophysical prospecting in different areas of China. The fields of magnetic, gravitational, electrical and seismic prospecting are represented. In addition, articles of a theoretical nature are also included such as the tectonic relationship of seismic activity in East Sikang, a note on some gravity anomalies, and a resume of seismological work in China. All but one of the articles are in English. It is in German and on a meteorological topic involving effects of heat exchange by warm and cold air masses. Business correspondence should be addressed to: Parker C. Chen, Institute of Meteorology, Academia Sinica, Pei-Chi-ko, Nanking, China, and manuscripts should be addressed to: Weng Wen-Po, Chinese Petroleum Corporation, 131 Kiangsi Rd., Shanghai, China.

R. A. GEYER

Geophysical Exploration, Vol. 1, No. 1 (1948). Pp. 63. Published by The Society of Exploration Geophysicists of Japan.

The primary reason for mentioning this new periodical is purely for historical purposes since this is Volume 1, Number 1 of the publication, and a review of a similar journal published in China appears elsewhere in this Reviews Section. The articles in this periodical are all written in Japanese although a number of them contain very brief English abstracts. According to the Table of Contents, articles on all the major geophysical prospecting methods are presented.

R. A. GEYER

Cybernetics or Control and Communication in the Animal and the Machine by Norbert Wiener. New York: Wiley and Sons, 1948.

This little book (194 pages) has some interest for two classes of geophysicists, namely, the seismic instrument designers and the interpreters of seismic records. In his third chapter (pp. 74–112) the

author considers "messages" and "noise." Usually we get "reflections" with "noise." The reflection is distinguished from the noise—to the extent that this distinction is possible—in terms of "relationships of order," for the reflection, and "relationships of disorder," for the noise.

Professor Wiener points out that (p. 79) "no operation on a message can gain information on the average." This is of special interest to us as we always feel that some operation such as filtering is necessary. It should be noted that filtering does *not* give us more information, but only makes it possible for us to see less information better! We thus raise the question "to what extent should the imperfections of human receivers of information be explicitly taken into account in such a theory as is being presented in the book under review?" As a practical matter, filtering not only helps, but in some cases, appears absolutely necessary, Nevertheless, filtering does reduce the amount of extractable information.

The author has attributed to J. von Neumann a quantitative valuation of "information" that is exceedingly interesting and may correspond reasonably well to our feelings in this matter in most cases but not always. For example, a rough calculation using this definition shows that the amount of information contained in a normal distribution is zero if the standard error is $\sigma = 0.31$. The variation is in the right direction, as reducing σ gives more information. This could perhaps be made more useful by adding a carefully selected constant to von neumann's measure, which measure is

$$\int_{-\infty}^{+\infty} \{(\log_2 f_1(x)\} f_1(x)\, dx$$

where

$$\int_{-\infty}^{+\infty} f_1(x)\, dx = 1,$$

and $f_1(x)$ contains all the information.

The present reviewer suspects that the rather wide audience, to which the book seems to be addressed, may, on the average, fail to feel the vital urgency of some of the mathematical problems. These problems are indeed urgent ones for those who are mathematicians and mathematical physicists, i.e. for the people who are capable of having these problems get under their skins. Fortunately most of the readers of this book will be more or less immune to some of these details of logical order and rigour. This is fortunate because said problems are so difficult to resolve.

This book can be skimmed because the subject is not yet at a very advanced stage of maturity. The possibility of the large-scale digital computers is a development of the last war time. The influence of this development on our understanding of ourselves and of our environment is potentially enormous, but as yet only potentially so.

Unfortunately the book was carelessly proof-read. The worst case is page 77 where five errors appear: the right-hand sides of equations (3.08) and (3.083) should both be one instead of zero; the line between equations (3.081) and (3.082) should read "Note that if $f_1(x, y)$ is of the form $\phi(x).\ \psi(y)$"; and each of the integrals in equation (3.082) should be equal to unity; and on page 106 the sentence in the fifth and sixth lines is incomplete. Also equation (3.09) appears to depend on x on the left but not on the right!

The book may be characterized as a preliminary and very stimulating account. It is a happy circumstance indeed that Professor Wiener has not waited until the subject has become fossilized before its publication.

C. HEWITT DIX

PUBLICATIONS RECEIVED

American Journal of Science, Vol. 246, No. 12 (December 1948), Vol. 247, No. 1 (January 1949).
American Petroleum Institute Quarterly, Vol. 19, No. 1 (January 1949).
Annali di Geofisica, Vol. I, No. 2 (April 1948)
Beitrage Zur Angewandten Geophysik, Band 9, Heft 2, 1944
Belluigi, A., (Separates)
Skin-effect e correnti vorticose nei suoli omogenei interessati da corrente alternata.
Sulle valutazioni grafico-analitiche di campi elettromagnetici dei giacimenti minerari.
Estratto delle pubblicazioni scientifiche.
Fondamenti di una nuova prospezione.
La ricerca dei combustibili fossili.
Le grandi Cosmogonie e le loro ripercussioni geo-giacimentologiche.
Mining Geophysical Prospecting International Institute.
Cartografie di campi elettromagnetici nei suoli a polarizzazione ellitica e loro impiego.
L'influenza dei fanghi nelle misure di resistivita elettricà nei fori di sonda non tubati.
Attivita scientifica.
La misura diretta dei campi elettromagnetici secondari dei suoli (il Mind).
I contatori Geiger e Muller ed il loro impiego nella indagine geofisica.
L'Elettrologia galvanica nei conduttori tridimensionali (suoli).
Bulletin de l'Ecole Polytechnique de Jassy, Tome 3, Fasc. 1 (Janvier a Juin 1948)
Bulletin of the Seismological Society of America, Vol. 38, No. 4 (October 1948)
Cronica Bibliografica (Instituto de Fisiografia y Geologia, Rosario, Argentina), Vol. I, 1947
Proceedings of the Cambridge Philosophical Society, Vol. 45, Part 1 (January 1949)
Canadian Geophysical Bulletin, Vol. II, No. 2 (April–June, 1948)
Die Eisen—und Manganerze der Schweiz, Geotechnische Serie XIII Lieferung 4 Band (1948)
Economic Geology, Vol. XLIV, No. 1 (January–February 1949)
Geofisica Pura e Applicata, Vol. XIII, Fasc. 3–4 (September–October 1948), Fasc. 5–6 (November–December 1948)
Institute of Petroleum Review, Vol. 2, No. 22 (October 1948), No. 23 (November 1948), No. 24 (December 1948)
Instituto de Fisiografia y Geologia:
El Puelchense de Buenos Aires y Su Fauna, Rosario, 1948.
Instituto Geofisico—Trieste, Prof. Carlo Morelli (Separates):
Sulla Costante Fondamentale Della Formula Ellissoidica Internazionale per la Gravita Normale, reprint from *Geofisica Pura e Applicata*, Vol. IX, Fasc. 1–2.
Teoria e Pratica dei Variometri Magnetiei da Compagna, 1947.
Nuovelle Contribution en Faveur d'un Systeme de Reference "International" Pour les Mesures de Gravite Relative.
Costanti Armoniche e NonArmoniche Delle Maree di Porto Lignano.
Analisi Perodale Delle Serie dei Livelli Marini di Trieste e Venezia.
La Rete Geofisica e Geodetica in Italia.
G L I Attuali Movimenti Verticalli.
Cento Anni di Osservazioni Meteoroligiche Esequite a Trieste.
Su Una Correzione per I Valoir Della Gravita.
Nr 186 Sulla Corrente Elettrica Verticale in Italia.
Journal of Applied Physics, Vol. 19, No. 12 (December 1948), Vol. 20, No. 1 (January 1949), No. 2 (February 1949).
Journal of the Institute of Petroleum, Vol. 34, No. 298 (October 1948), No. 299 (November 1948).
Journal of Petroleum Technology, Vol. I, No. 1 (January 1949), No. 2 (February 1949).
Nafta (Pazdziernik-Listopad, 1948), Rocznik IV, Numbers 10, 11 and 12.
A Philosophy for Conservation, Circular No. 33, Pennsylvania State College Bulletin.
The Review of Scientific Instruments, Vol. 19, No. 11 (November 1948), No. 12 (December 1948), Vol. 20, No. 1 (January 1949).
Terrestrial Magnetism and Atmospheric Electricity, Vol. 53, No. 4 (December 1948).

CONTRIBUTORS

ROBERT J. WATSON

ROBERT J. WATSON graduated from the University of Toronto in 1925 with a B.A. in geology, followed by an M.A. in 1926. Field experience in pre-Cambrian geology, graduate studies in geology, physics and mathematics at California Institute of Technology and the University of Colorado, instructing in geology and geophysics and a year of field research in electrical methods led to a Ph.D. at the University of Colorado in 1933.

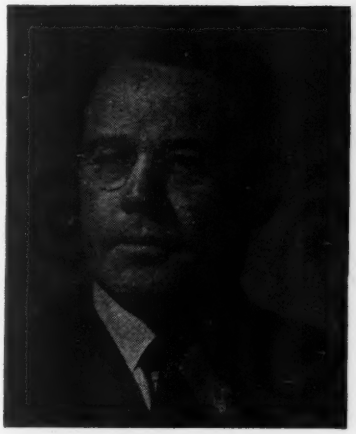
Joining the Carter Oil Co. in 1936, Dr. Watson has continued with Jersey Standard Companies. In 1939–40 he supervised and interpreted magnetic and gravity surveys for Standard Oil Co. of Egypt and from 1946–48 he was Exploration Manager for Standard Oil Co. (Bahamas) Ltd. He is now again with Carter as a geophysical consultant to foreign affiliates of Standard Oil Co. (N.J.).

Dr. Watson is a member of the Society of Exploration Geophysicists and the American Geophysical Union.

W. B. AGOCS received his B.S. degree in mechanical engineering from Lehigh University in 1934, his M.S. in physics in 1944, and his Ph.D. in physics in 1946. From 1934 to 1940 he was an employee of the Gulf Research and Development Company as geophysicist and party manager, spending four years of the period in Venezuela. From 1940 until 1943 he was a graduate student and graduate assistant in physics at Lehigh University. In 1934 he was employed as chief geophysicist by the Venezuelan Atlantic Refining Company in which position he remained until 1945. He was assistant professor of physics at Lehigh University from 1946 to 1948, and from 1948 to date, chief geophysicist for the Venezuelan Atlantic Refining Company.

Mr. Agocs is a member of Sigma Xi, The American Physical Society, The Institute of Engineering, and the Society of Exploration Geophysicists.

W. B. AGOCS



OBED C. HAYCOCK

OBED C. HAYCOCK was born in Panguitch, Utah, October 5, 1901. He received his B.S. degree in electrical engineering from the University of Utah and his M.S. in the same subject from Purdue University. At present he is a professor of electrical engineering at the University of Utah, primarily responsible for courses in electronics and communications.

During World War II, Professor Haycock joined the staff of Rutgers University working on the jungle acoustics in Panama. At present, in addition to his teaching assignments, he is associate director of the Upper-Air Research Project under a contract with the Air Materiel Command.

Besides being a senior member of the I.R.E., Professor Haycock is a member of the A.I.E.E. and a past chairman of the Utah Section of that organization. He is also a member of Tau Beta Pi and the American Society for Engineering Education.

EVAN C. MADSEN

EVAN C. MADSEN was born on June 22, 1920 in Manti, Utah. He received his B.S. degree in electrical engineering in 1944 from the Illinois Institute of Technology and his M.S. degree in 1948 from the University of Utah. In 1944, as a lieutenant (j.g.) in the U. S. Navy, he received training in radio and radar at Harvard University and the Massachusetts Institute of Technology. This training led to an assignment as the radio and radar maintenance officer under the Atlantic Fleet Air Command. He served in this capacity until his separation from the service in 1946.

From 1946 he has been an instructor of electrical engineering at the University of Utah and is now engaged in research on the Army Air Force Upper-Air Research Program.

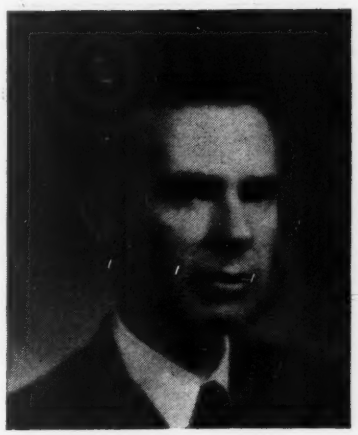
Mr. Madsen is a member of Sigma Xi, Tau Beta Pi, Eta Kappa Nu, Rho Epsilon, and the Institute of Radio Engineers.

STANLEY HURST

STANLEY HURST was born in New York City, February 20, 1925. He received his elementary education in Ogden, then attended Weber Junior College, The Agricultural and Technical College of Texas, and the University of Utah. He received his B.S. degree in 1947 and his M.S. degree in 1948, both in electrical engineering, from the University of Utah. At present he is pursuing his graduate studies at the Massachusetts Institute of Technology. Mr. Hurst is a member of Tau Beta Pi and Sigma Xi.

FREDERICK ROMBERG received his B.A. degree from the University of Texas in 1929 and his A.M. in physics from Harvard in 1932. He spent the year 1929–30 in the Geophysical Department of the Humble Oil and Refining Company and 1932–33 in the Physics Department at Harvard. In 1933 he was employed by Geophysical Service, Inc. He was for some years chief of a seismograph field party, and later worked on the development and application of new interpreting methods. At present he is engaged in maintenance and development of gravity meters in the LaCoste-Romberg laboratories. He is a member of the American Geophysical Union and of the Society of Exploration Geophysicists.

FREDERICK ROMBERG



VIRGIL E. BARNES

VIRGIL E. BARNES was born in 1903 in Chehalis, Washington. He received his B.S. degree in 1925 and his M.S. in 1927, both from the State College of Washington, and his Ph.D. in 1930 from the University of Wisconsin. His summer work has included the following: Washington Geological Survey, 1924–1927; Wisconsin Geological Survey, 1928; Dominion Explorers, Ltd., Canada, 1929. From 1930–1931 Dr. Barnes was with the American Petroleum Institute and from 1933–1935 with the U. S. Geological Survey. He has been with the Bureau of Economic Geology at the University of Texas since 1935. His publications have included the following subjects: Cambrian, Ordovician, and Devonian stratigraphy; economic geology; mineralogy; tektites; meteorites; oil-field water; earth temperatures; and joint papers correlating geology and gravity.

R. B. RICE

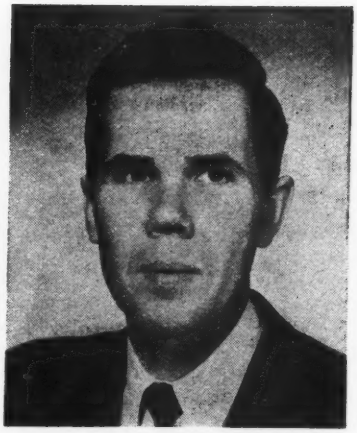
R. B. RICE received his B.A. degree in mathematics and physics from the College of Wooster, Wooster, Ohio, in 1941. He joined Phillips Petroleum Company in the summer of 1941 as a reservoir engineer in the Production Department. From 1941 to 1945 he taught and did graduate work in the Department of Mathematics, Ohio State University. In 1945 he returned to Phillips as a process and design engineer in the Gasoline Department. Since 1946 he has held the position of mathematical physicist in the Geophysical Section of the Research Department. He is also on the extension staff of Oklahoma A. and M. College.

Mr. Rice is a member of the American Mathematical Society, the Mathematical Association of America, American Physical Society, the Geophysical Society of Tulsa, and the Society of Exploration Geophysicists.

D. C. SKEELS

DORR COVELL SKEELS graduated with a B.A. degree in physics and mathematics in 1930 from the University of Montana. He was a Rhodes Scholar from Montana in 1930. He received his B.A. in geology from Oxford in 1933, and his Ph.D. in geology from Princeton University in 1936. From 1936–1938 he did seismic field work and computing for the Carter Oil Co. and from 1938–1946 he was a research geophysicist for the Standard Oil Development Co. In 1946 he joined the Standard Oil Co. (N.J.) with whom he is still associated. Dr. Skeels' principal field of activity and research has been the study of gravity data and correlations between gravity and geology.

JAMES H. LEONARD received his A.B. degree from Fresno State College in 1942 and his M.S. degree from the California Institute of Technology in 1943. From 1943 until 1946 he served in the Army Air Forces as a meterologist. From 1947 until 1948 he served as chief computer for the Western Geophysical Company. Since early in 1949 he has been with the Western Gulf Oil Company in their Bakersfield laboratory. He is a member of the American Meteorological Society and the Society of Exploration Geophysicists.



JAMES H. LEONARD

In addition, reference is cited to an earlier issue for the biography of: Raoul Vajk, Vol. XII, No. 2, (April, 1947).

SOCIETY ROUND TABLE

SOCIETY OF EXPLORATION GEOPHYSICISTS *COUNCIL*

The governing body of the Society, called the "Council," is composed of the Officers of S.E.G., District Representatives elected by the Local Sections, District Representatives appointed by the President and Chairmen of the Standing Committees. Only the elective offices of the Council carry the power to vote on its actions. Following are the members of the incoming and outgoing Council which met in St. Louis, Mo., on March 15, 1949.

Name		*Title*
L. L. Nettleton		President
E. V. McCollum		Secretary-Treasurer
Andrew Gilmour		Vice-President
M. King Hubbert		Editor
Cecil H. Green		Past President
J. J. Jakosky		Prior Past President
W. H. Courtier	Outgoing	District Representative (Tulsa)
J. E. Hawkins		District Representative (Tulsa)
J. P. Garner		District Representative (Tulsa)
W. W. Newton		District Representative (Dallas)
A. E. McKay	Outgoing	District Representative (Dallas)
Paul Nash		District Representative (Dallas)
W. J. Osterhoudt	Outgoing	District Representative (Houston)
Roy L. Lay		District Representative (Houston)
H. G. Patrick		District Representative (Houston)
R. L. Palmer		District Representative (Houston)
James L. Morris		District Representative (Ft. Worth)
Dean Walling	Outgoing	District Representative (Pacific Coast)
Joe B. Hudson		District Representative (Pacific Coast)
John Sloat		District Representative (Pacific Coast)
J. B. Macelwane, S.J.		Chairman, Standing Committee on Education
Roland F. Beers		Chairman, Standing Committee on Honors & Awards
V. L. Jones		Chairman, Standing Committee on Student Membership

COMMITTEES FOR THE YEAR ENDING MARCH 1949

Standing Committees

Nominations

L. L. Nettleton, *President* — Cecil H. Green, *Past President*
J. J. Jakosky, *Prior Past President*

Honors and Awards:

Roland F. Beers, *Chairman* — M. King Hubert
W. T. Born — Frederick E. Romberg
Frank Goldstone — Paul Weaver

Program and Arrangements: Andrew Gilmour, *General Chairman*

Dallas:

K. E. Burg, *Chairman* — O. C. Clifford, Jr.
E. D. Alcock — W. B. Hogg
Dayton H. Clewell — M. P. Jones

Eastern Region:

Sigmund Hammer, *Chairman* — O. F. Ritzmann
D. C. Skeels

Fort Worth: A. A. Hunzicker
Houston: J. C. Pollard
Pacific Coast: M. W. Harding
Shreveport: L. F. Fischer
Tulsa: Francis F. Campbell

Publications:

M. King Hubbert, *Chairman*
Richard A. Geyer
Florence Robertson
C. Hewitt Dix
Milton B. Dobrin
Noyes D. Smith
Henry R. Joesting

Education:

Rev. J. B. Macelwane, S.J., *Chairman*

Student Membership:

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J. H. Hodgson
Darrell S. Hughes
Ralph Jackson
L. B. Slichter
C. Hewitt Dix
H. V. W. Donohoo
Ralph C. Holmer
J. C. Menefee
Sylvain Pirson

SPECIAL COMMITTEES

Radio Frequency Allocations: R. D. Wyckoff, *General Chairman*

Dallas: W. R. Mitchell
Ft. Worth: V. Robert Kerr
Houston: W. M. Rust, Jr.
Los Angeles:
B. W. Sorge, *Chairman*
Dean Walling
H. R. Thornburgh
R. C. Dunlap, Jr.
Shreveport:
Richard Brewer, *Chairman*
J. E. Walker
Herbert A. Morriss
Glenn J. Baker
Tulsa:
Daniel Silverman, *Chairman*
E. M. McNatt
Joseph A. Sharpe
J. E. Hawkins
W. T. Born
A. J. Hintze

Distinguished Lecture Tours:

Francis F. Campbell, *Chairman*
John H. Wilson
R. A. Geyer

Safety: A. E. McKay, *Chairman*

Public Relations:

George E. Wagoner, *Chairman*
Paul L. Lyons, *Vice Chairman*
Dallas:
J. W. Horn
W. G. Smiley, Jr.
Forth Worth: H. E. Ittner
Houston: Earle W. Johnson
Pacific Coast: Phillips J. Kempsky
Shreveport: B. B. Burroughs
Tulsa: H. M. Thralls

Annual Review of Geophysical Activity:

E. A. Eckhardt, *Chairman* A. A. Brant
Herbert Hoover, Jr.

DELEGATES TO INTERNATIONAL MEETINGS

J. P. Schumacher, Delegate to *International Geological Congress*, London, England
Walter E. A. Ruska, Delegate to *International Union of Geodesy and Geophysics, Oslo, Norway*

S.E.G. DIRECTORS

American Geological Institute

E. A. Eckhardt (Term expired March 1949)
L. L. Nettleton (Term expires March 1950)

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the President within thirty days. (Names of references appear in parentheses after the name of each nominee.)

ACTIVE

Arthur Ira Bartow (C. H. Green, J. H. Pernell, G. A. Berg)
Donald Vernon Bigelow (H. R. Moorman, R. H. White, H. J. Kidder)
David Franklin Bleil (H. R. Joesting, J. H. Swartz)
William N. Booth (Bill Matthews, T. P. Ellsworth, John Sloat)
John William Bowden (R. Lockwood, L. I. Brockway, O. Erdman)
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Charles Hemphill Fay (M. K. Hubbert, N. D. Smith Jr., F. A. Van Melle)
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Phil Hugh Garrison (Karl Dyk, K. C. Thompson, W. A. Matthews)
Peter Warren Gester (J. A. Long, A. L. Snow, A. W. Farmilo)
John Henderson Guntharp (H. M. Houghton, Andrew Gilmour, F. W. Borman)
Charles Franklin Hadley (Daniel Silverman, J. D. Eisler, J. R. Cooper)
Tyrus Raymond Hartley (P. E. Nash, W. B. Roper, H. E. Granberry)
Louis Howard Inman (W. M. Wells, W. G. Green, C. E. Duller)
Earle Winston Johnson (E. E. McDermott, T. O. Hall, Chester Sappington)
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Louis Franklin Lockard (A. C. Austin, R. F. Aldredge, H. M. Thralls)
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Everett Clinton Martin (C. C. Zimmerman, H. W. McDonnold, Alexander Wolf)
Louis B. McManis (J. R. Cooper, C. E. Buffum, Daniel Silverman)
Harold Leroy Mendenhall (A. J. Hintze, W. H. Courtier, J. L. Hollis)
Dolph Beadle Moore (J. E. LaRue, M. M. Slotnick, H. V. Goss)
Peter Mrosovsky (F. A. Van Melle, L. K. Mower, A. Gilmour)
James Richard New (F. E. Brown, F. R. Smith, W. O. Bazhaw)
Decatur O'Brien (H. G. Patrick, M. M. Slotnick, D. P. Carlton)

William Wesley Ogden (G. D. Lambert, C. C. Ludwick, R. F. Christy)
Paul Burnett Powell (H. G. Patrick, R. S. Duty, A. G. Starr)
Newton Joseph Rabensburg Jr. (F. J. Agnich, F. A. Moore, G. J. Long)
Guy Marvin Ratliff (H. M. Dawson, Thornton Davis, Leland Snow)
Walter Houston Roane (A. J. Hintze, W. H. Courtier, D. J. Wolfe)
Cletus Daniel Roemer (W. O. Bazhaw, F. E. Brown, J. B. Macelwane, S. J.)
Samson George Sargis (L. B. Slichter, C. B. Aiken, E. G. Leonardon)
Peter Paul Schiebl Jr. (E. G. Schempf, R. A. Peterson, B. W. Sorge)
Jean Stephen Spencer (W. J. Osterhoudt, W. B. Lee Jr., Chester Sappington)
John Phillip Strange (R. E. Hartline, J. R. Cooper, G. R. Newton)
Homer Carroll Talley (L. A. Scholl Jr., R. L. Lay, A. A. Hunzicker)
Douglas Frank Warner (H. H. Andrews, C. E. McClure, T. A. Manhart)
Sten Sture Tobias Werner (H. E. Hawkes, Hans Lundberg, Per Geijer)

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Robert Byron Gaines Jr. (K. C. Thompson, W. A. Matthews, E. D. Alcock)
Harold Lloyd Gaither (C. H. Green, F. J. Agnich, A. E. Storm)
Paul Martin Hanahen (W. J. Osterhoudt, J. E. McGee, W. B. Lee Jr.)
Stanley Greely Hardison (L. F. Guseman, L. G. Cornish, D. J. Wolff)
Junius John Hayes (H. V. W. Donohoo, C. E. Jacob, R. S. Lewis)
Oran Clay Henderson (F. J. Angnich, C. H. Green, F. A. Moore)
Delmar Ellis Hill (C. H. Green, R. C. Dunlap, E. A. Kiesler)
Emmett Talmadge Hill Jr. (O. C. Clifford Jr., A. E. McKay, C. H. Hightower)
Lloyd Johnson (F. J. Agnich, K. E. Burg, C. H. Green)
Myron T. Kozary (S. J. Pirson, L. O. Bacon, Sigmund Hammer)
John Milton Lankton (R. H. Tucker, J. E. Spencer, C. P. Durant)
Randall Ross Lemaster (F. B. Smith, W. L. Homan, J. R. Winnek)
Donald Leslie Lohrentz (Martin C. Kelsey, E. F. McMullin, J. F. Rollins)
Lawrence Broderick Luhrs (S. J. Pirson. L. O. Bacon)
Montie Charles Mantooth (R. C. Dunlap Jr., C. H. Green, K. M. Lawrence)
Wendell Vaden Mickey (R. D. DeJournette, C. J. Donnally, Dean Walling)
Lloyd C. Miller (L. L. Nettleton, R. A. Peterson, Lloyde Metzner)
Cornelius Sebastian Moynihan (L. G. Ellis, W. E. Hollingsworth, A. G. Ebberts)
Carlton Henry Olson (L. J. Richards, L. F. Athy, H. R. Prescott)
Russell Nelson Ostreim (R. H. Ray, E. W. Frowe, W. R. Griffin)
Claven Estell Patton (K. H. Waters, B. J. Sorrells, E. D. Alcock)
Calvin Greer Percy (G. F. McReynolds, D. H. Gardner, W. M. Rust Jr.)
Justus Verner Price (E. J. Stulken, J. W. Thomas, G. J. Kohler Jr.)

Richard Hoyt Rainey (C. H. Green, K. E. Burg, F. J. Agnich)
William Allen Rasco (J. W. Byers, R. L. Palmer, C. T. MacAllister Sr.)
Robbie Gene Rutherford (R. C. Hilton, O. B. Manes, L. K. Mower)
James Lee Salyer (Leland Snow, Gordon Kirby, Homer Roberts)
Charles Willard Smith (M. C. Kelsey, J. F. Rollins, H. H. Moody)
Maurice Jean Stouse Jr. (L. B. Rogers, H. G. Patrick, R. S. Duty Jr.)
Clayton Stephenson Valder Jr. (F. R. Walling, L. D. Ervin, D. W. Ratliff)
Howard Burton Warren (H. C. Moore, J. P. Garner, C. C. Zimmerman)
John Rex Wayland (J. C. Menefee, Rex White, George Isensee)
Robert Harold Wegener (J. H. Todd, J. W. Northrop III, W. H. Ware)
James Ernest Wilson Jr. (F. Goldstone, G. D. Lambert, L. K. Mower)
William Howard Wilson (K. C. Thompson, W. A. Matthews, D. W. Ratliff)
Billy Winn (W. J. Harkey, E. L. Fetzer, W. H. Amis)
Thomas Eugene Young (C. C. Ludwick, R. F. Christy, G. D. Lambert)

TRANSFER FROM ASSOCIATE TO ACTIVE

Ernest William Dissler Revill M. Rogers Clayton N. Winn

TRANSFER FROM STUDENT TO ASSOCIATE

George E. Anderson Jr. Richard F. Hagemann
Anthony M. DiRenzo Pierson M. Ralph

REINSTATEMENT TO ACTIVE

Eugene W. Hunt E. J. Jasinski Fritz Kaselitz
John R. Myers Victor Vacquier

RESIGNATIONS

Gordon E. Bowler, Active W. Obier Martin, Associate
C. Russell Hale, Associate J. Neufeld, Active
W. T. Holser, Associate Chesley B. Pickle, Associate
A. B. Manning, Associate J. M. Rich, Active
Robert J. Urick, Associate

PAPERS PRESENTED AT MEETINGS OF THE LOCAL SECTIONS

DALLAS GEOPHYSICAL SOCIETY

February 14, 1949

Use of Electric Logging Equipment in Seismic Exploration, W. J. Osterhoudt, Gulf Research and Development Co., Houston.

FORT WORTH GEOPHYSICAL SOCIETY

The examination and study of public relations as applied to the geophysical industry is one of the projects chosen by the Fort Worth Geophysical Society for the current year. A final report on this subject will be completed and made available to other local sections.

Affiliation of the Fort Worth Geophysical Society as a local section of the S.E.G. became official in August of 1948. The society was organized by a local group of actively interested geophysicists and held its first meeting January 26, 1948 with V. Robert Kerr presiding. Subsequently officers were elected and serving during 1947 were R. W. Dudley, Pure Oil Company, President; P. H. Ledyard, Southern Geophysical Company, Vice President; Erik Thomsen, Stanolind Oil and Gas Company, Secretary-Treasurer.

The Fort Worth Section is now in its second year of existence, and has a membership of forty-three. Current officers are Sidon Harris, Southern Geophysical Company, President; A. A. Hunzicker, The

Texas Company, Vice President; G. H. Harrington Jr., Independent Exploration Company, Secretary-Treasurer.

H. E. ITTEN, *Chairman*
Fort Worth Public Relations Committee

ARK-LA-TEX GEOPHYSICAL SOCIETY, SHREVEPORT

January 27, 1949 (Luncheon)

Seismograph Interpretation and Special Fault Problems, a moving picture produced by Seismograph Service Corporation, Tulsa.

GEOPHYSICAL SOCIETY OF TULSA

December 9, 1948 (Attendance: 150 members and guests)

Symposium: *Effects of Instruments on Seismic Interpretation*, E. M. McNatt, The Carter Oil Company, *Chairman.*

General Considerations, W. T. Born, Geophysical Research Corp.

Effects of Filters on Reflection Character, J. A. Stafford, Century Geophysical Corp.

Effects of Indiscriminate Mixing, N. J. Christie, United Geophysical Co., Inc.

The papers were presented from the point of view of the operating and interpretative groups. Examples of field data and the effects of general instrumental characteristics on seismic records were discussed.

January 13, 1949 (Attendance: 116 members and guests)

Symposium: *Correlation of Seismic Reflections with Geological Markers*, H. M. Thralls, Seismograph Service Corp., *Chairman.*

Can Geophysical Reflections be Correlated with Geological Horizons, E. J. Handley, Century Geophysical Corp.

Examples of Correlation Between Seismic Reflections and Geological Markers, Neal Clayton, Republic Exploration Company

Identification of the Midway Shale on Seismic Records in Louisiana and Mississippi, Francis F. Campbell, Amerada Petroleum Corp.

Examples of Failures in Correlation of Seismic Events with Geological Markers, H. M. Thralls

Specific data on seismograph records and examples illustrating the problem were presented. A round table discussion, in which the members took an active part, was conducted concerning the types of geological markers which can be identified on seismograms and the causes of past failures in identification of seismic reflections.

February 10, 1949 (Attendance: 73 members and guests)

Steep-Dip Seismic Computing Methods, R. B. Rice, Phillips Petroleum Company, Bartlesville

Precision of Aeromagnetic Observations, Joseph A. Sharpe, Frost Geophysical Corp.

Mr. Rice presented slides to illustrate different velocity assumptions for computing seismic data in areas of steeply dipping beds. He discussed the geological conditions controlling these assumptions and stated the formulas for depth, dip, and displacement which correspond to them. The application of these formulas to several types of structure were shown.

Dr. Sharpe presented maps of a four-township area near Tulsa which was surveyed twice with an aeromagnetometer. He compared the data from the two independent surveys.

February 17, 1949 Special Meeting (Attendance: 85 members and guests)

Near Surface Seismic Refraction Mapping, Rev. Daniel Linehan, S. J., Weston Seismological Laboratories, Boston College, Weston, Mass.

Father Linehan discussed near surface procedures and interpretational techniques for deter-

mining depth to the water table and to bed rock. He related his experience in the discovery of buried remnants of concrete constructions by methods which may be adaptable to location of buried boulders and limestone caves.

COLORADO SCHOOL OF MINES SOCIETY OF STUDENT GEOPHYSICISTS

January 21, 1949 (Attendance: 60 members and guests)

Some Limiting Factors and Problems of Mining Geophysics, A. A. Brant, University of Toronto, Canada

With his paper, Dr. Brant showed slides of geophysical results and a colored movie taken in the Big Bear Lake Country of Canada. This meeting was considered one of the society's most successful to date.

At a business meeting of the society on January 13, 1949, it was decided to elect all past and future speakers to honorary membership. This action was taken to show the appreciation of the students for the effort of these speakers in presenting their papers before the group. Honorary life membership cards have been sent to A. A. Brant, R. L. Fitzgerald, John T. Geer, E. V. McCollum, James L. Morris, T. W. Nelson, Jack W. Peters and John H. Wilson Sr.

C. W. BOWLBY
Secretary-Treasurer

ANNOUNCEMENTS

ENGINEER'S DAY COMMITTEE COLORADO SCHOOL OF MINES

Golden, Colorado

The program for the fifteenth annual Engineers' Day at the Colorado School of Mines on April 22–23, *is now complete* according to an announcement made this week by Chairman J. R. Medaris. The event will feature technical sessions in geology, geophysics, mining, metallurgy, petroleum production, and petroleum refining as well as tours, contests, and many industrial and governmental exhibits. Everyone interested in engineering, particularly that of the mineral fields, is cordially invited to attend the Engineers' Day activities. Registration will begin at 9 A.M. on Friday, April 22. Information regarding hotel reservations in Denver can be obtained by writing the Engineers' Day Committee, Golden, Colorado, attention: Mr. George H. Fentress.

A definitely added feature will be the luncheon in honor of Dr. M. M. Slotnick of the Humble Oil & Refining Company. Dr. Slotnick will address the Society of Student Geophysicists and their guests. His topic will be "The Geophysics of the Gulf Coast Area."

Following is the schedule of Friday afternoon technical sessions and the prominent engineers who will deliver papers at each:

Petroleum Engineering—Dean A. McGee, vice president of Kerr-McGee Oil Industries, L. L. Nettleton, president of the Society of Exploration Geophysicists, A. L. Solliday, executive vice president of the Stanolind Oil and Gas Company.

Mining Engineering—H. A. Walker, general manager of the Homestake Mining Company, M. B. Kildale, chief geologist of the International Smelting & Refining Company, Dart Wantland of the U. S. Bureau of Reclamation.

Metallurgical Engineering—Max W. Bowen, vice president of the Golden Cycle Corporation, F. R. Anderson of the Gardner-Denver Company.

Petroleum Refining Engineering—C. W. Perry of the Phillips Chemical Company; A film on cracking will be presented by the Standard Oil Company.

Space is available for about fifteen more exhibits. Organizations may secure complete information from J. R. Medaris, Box 147, Golden, Colorado. There is no charge for display space. Exhibitors, however, are asked to provide their own backdrops and tables.

SHELL FELLOWSHIPS

The Shell Fellowship Committee announces that the graduate Fellowship Program, established by Shell Union Oil Corporation and its associated companies in the United States, will be continued through the 1949–50 academic year. These fellowships, which include payment of all fees and tuition in addition to a stipend of $1,200 and an allotment of $300 to the department for equipment and research expenses, are designed to aid deserving students toward advanced degrees in scientific and technical fields, including chemistry, geology, geophysics, and physics, as well as chemical, mechanical, geological and petroleum engineering fields. The program embraces 44 fellowships at 36 colleges and universities, and the recipients of these awards are in no way under obligation to Shell.

The program is administered by a committee of senior staff members representing the Shell Union companies. However, selection of the fellows and the type of research to be pursued is determined by the department of study of the participating schools. The awards are intended primarily for students in the final years of doctorate study but may be held by other graduate students.

JOURNAL OF GEOPHYSICAL RESEARCH

It has just been announced that Dr. Merle A. Tuve has succeeded Dr. John A. Fleming as editor of the well-known geophysical journal *Terrestrial Magnetism and Atmospheric Electricity* (1896–1948) and that beginning with Volume 54 for the current year, the name of the journal has been changed to *Journal of Geophysical Research*. An extensive panel of associate editors has also been announced.

As a first step toward greater usefulness in the future, the magazine will be improved as an avenue of publication for the scientific aspects of geophysics as distinguished, at least in many cases, from research and development work in geophysics directed toward more practical ends. This policy means no basic change in the international service to present subscribers, but rather a considerable extension of the utility of the periodical. Appropriate scientific articles are invited by the editors, and a limited number of new subscriptions will be accepted.

FOURTH EMPIRE MINING AND METALLURGICAL CONGRESS

The Fourth Empire Mining and Metallurgical Congress convened by the Empire Council of Mining and Metallurgical Institutions will be held in Great Britain from 9th to 23rd July, 1949.

The chief object of the Congress is to afford an opportunity for scientists, engineers and others concerned with the mining and metallurgical industries to meet and discuss technical progress and problems, including the development of the mineral resources of the Commonwealth.

The programme will be divided as follows:—

July 9th to 12th—London. Inaugural Meeting, Government Reception, Banquet at Guildhall and a number of excursions and visits.

July 13th to 17th—Oxford. Technical Sessions. The main subjects for discussion will be:

Mineral Resources of the Commonwealth.

Modern Methods of Prospecting.

Physiological and Psychological Effects of Heat and Humidity on Workers in Deep Mines and in Metallurgical Works.

Petroleum (with special reference to the World Oil Position, Oilwell Drilling Practice and its application to Petroleum Exploration).

Coal (with special reference to resources of the Commonwealth, the Characteristics of Empire Coals and Modern Coal-Mining Practice in Great Britain).

Present-Day Trends in Mineral Dressing.

Metallurgy and Metallurgical Industries.

July 18th to 23rd—Excursions. Visits based on Cardiff, Cornwall, Edinburgh, Manchester, Newcastle-upon-Tyne, Sheffield and Stratford-upon-Avon will be made to collieries, iron and steel works, hydro-electric schemes, shipbuilding yards and other places of technical interest, together with a number of excursions of historical and general interest.

Further information may be obtained on application to:—

The Joint General Secretaries,
Fourth Empire Mining and Metallurgical Congress,
436, Salisbury House,
Finsbury Circus,
London, E.C.2.

London, January, 1949.

PERSONAL ITEMS

H. W. STRALEY III, consulting geological and geophysical engineer, Box 5532, Friendship Station, Washington 16, D. C., and Princeton, West Virginia, spent most of the early summer of 1948 in Oklahoma in conjunction with a minerals survey of the eastern half of the state under the joint sponsorship of the Public Service Company of Oklahoma, Tulsa, and A & M College, Stillwater, Oklahoma.

E. L. DEGOLYER, L. W. MACNAUGHTON and RALPH J. PRYOR have been elected directors of Republic Natural Gas Company.

CHARLES W. OLIPHANT, president of Oliphant Laboratories, Inc., Tulsa, has received a certificate of appreciation from the Army and Navy for aiding in the development of a radar jamming device during the war.

RONALD K. DEFORD has resigned as chief geologist for Argo Oil Corporation, and has joined the faculty of the University of Texas. He will be in charge of special projects in the graduate division of the school of geology.

C. H. MCALISTER has resigned as chief geophysicist for Sunray Oil Corporation, and has announced the opening of his own offices in Tulsa as a consulting geophysicist. He will specialize in the review and reinterpretation of seismic data in the Mid-Continent and Gulf Coast areas and the supervision of current geophysical activities.

V. J. MERCIER has been elected chairman of the Kansas chapter of A.I.M.E. He is district engineer for Lane-Wells Company, Wichita.

JOE B. HUDSON, Humble Oil and Refining Co., Los Angeles, California, has been elected District Representative for the Pacific Coast Section, S. E. G. He will succeed Dean Walling, whose term expired March 15, 1949.

J. E. HAWKINS, Seismograph Service Corp., has been elected by the Geophysical Society of Tulsa to serve as District Representative.

ERNEST A. KIESLER has been promoted to the position of District Supervisor in the Pacific Coast supervisory staff of Geophysical Service Inc. His offices will be at 126 George Hay Building, Bakersfield, California.

HERBERT HOOVER JR., President of United Geophysical Company, is presently in Venezuela inspecting his company's operations in that area.

CAPT. FRANK E. WILLIAMS, Student Member, graduated February 17, 1949 from the Air Force Communications School at Scott Air Force Base, Illinois it was announced by the base commander. Captain Williams served as a pilot with the 8th Air Force during World War II. After thirteen missions, he was taken as a German Prisoner of War. He wears the Distinguished Flying Cross, Air Medal, European Theater of Operations Ribbon, and Purple Heart.

McCollum Exploration Company and McCollum Laboratories, Inc. have moved to their new office building at 1025 South Shepherd Drive, Houston 19, Texas. Their new mailing address is P.O. Box River Oaks Station, Houston 19, Texas.

REESE H. TAYLOR, president of the Union Oil Company of California, has been elected president of the Western Oil and Gas Association.

WAYNE H. DENNING has been appointed Area Supervisor for United Geophysical Company's California and West Coast Division, with headquarters in Pasadena, California. Mr. Denning spent seven years, from 1940 through 1947, in Brazil in charge of United's activities in that country. He more recently was in charge of the company's geophysical activities in Puerto Rico.

CHARLES G. FAUBION has been appointed party chief of Seismograph Party No. 6 with the Atlantic Refining Co. now located in Franklin, La. at Box 241.

EDGAR R. LOCKE has been appointed manager of the exploration department of Mid-Continent Petroleum Corp., with headquarters in Tulsa. He is in charge of all geological and geophysical operations for the company. His address will be Box 381, Tulsa 2, Okla.

WAYNE A. PHARES has been appointed area supervisor for gravity operations of the United Geophysical Company of Canada. He will make his headquarters in Calgary, Alberta, Canada.

W. L. HOMAN, formerly seismologist for Petty Geophysical Engineering Co., has opened a district office for Republic Exploration Co. at 210 Leggett Building, Midland, Texas.

NORMAN J. CHRISTIE has been appointed area supervisor of United Geophysical Company for the Mid-Continent and Gulf Coast Division of that company with headquarters in Tulsa, Okla.

J. BRIAN EBY, Houston consulting geologist, has been elected president of the Texas Academy of Science.

IRA H. CRAM, formerly manager of exploration for The Pure Oil Company in Chicago, has been elected vice president at the head of the exploration department of Continental Oil Company, Ponca City, Okla. He was associated with Pure for almost nineteen years.

P. E. NARVARTE, consulting geophysicist, announces the removal of his offices from the Insurance Building to the American Hospital & Life Building in San Antonio (5) Texas.

JAMES ROY MAXEY, formerly with Wichita Exploration Company, has joined Deep Rock Oil Corp. as superintendent of geophysics. His address is Box 1051, Tulsa 2, Okla.

ODELL C. OLSON has resigned as district engineer, Oil and Gas Division, Railroad Commission of Texas, and is now production engineer with Fred M. Manning, Inc., at Breckenridge, Texas.

K. A. ROBERTSON has been appointed vice president of United Geophysical Company of Canada and will make his headquarters in Calgary, Alberta, Canada. He also is area supervisor of the Canadian and Rocky Mountain division of the company.

E. GLENN ALBRIGHT, formerly with The Atlantic Refining Company, has joined The Richmond Exploration Company as seismologist with headquarters in Maracaibo, Venezuela. He may be addressed c/o REXCO, Apartado 93, Maracaibo, Venezuela.

SOCIETY OF EXPLORATION GEOPHYSICISTS

CONSTITUTION

Article I.	Name	Article X.	Meetings
Article II.	Object	Article XI.	Local Sections
Article III.	Membership	Article XII.	Districts
Article IV.	Code of Ethics	Article XIII.	Affiliated Societies
Article V.	Election, et cetera, of Members	Article XIV.	Committees
Article VI.	Officers	Article XV.	Business Manager
Article VII.	Duties of Officers	Article XVI.	Review by Members
Article VIII.	Council	Article XVII.	Bylaws
Article IX.	Executive Committee	Article XVIII.	Amendments to the Constitution

CONSTITUTION

(As amended to August 26, 1948)

Article I. Name

Section 1. The Society shall be called the "Society of Exploration Geophysicists."

Article II. Object

Section 1. The objects of this Society shall be to promote the science of geophysics especially as it relates to exploration and research, to foster the common scientific interests of geophysicists, and to maintain a high professional standing among its members.

Article III. Membership

Section 1. The membership of this Society shall consist of persons elected and qualified in accordance with the Constitution and Bylaws of this Society at the time of such election.

Section 2. The membership of this Society shall consist of Honorary Members, Active Members, Associate Members, and Student Members.

Section 3. To be eligible to election to Honorary Membership a person shall, in the unanimous opinion of the Standing Committee on Honors and Awards and the Council, have made a distinguished contribution to geophysics or a related field which warrants exceptional recognition.

Section 4. To be eligible to election to Active Membership an applicant must have been actively engaged in practising or teaching geophysics or a related field for not less than eight years (up to four years as a student in a recognized college or university may be counted toward this total) of which at least three years must have involved work of a responsible nature calling for independent judgment and the application of geophysical or geological principles.

Section 5. To be eligible to election to Associate Membership, an applicant must be actively interested in geophysics.

Section 6. To be eligible to election to Student Membership an applicant must be a graduate or undergraduate student in good standing in residence at a recognized university or college.

Section 7. An Honorary Member or Active Member shall enjoy all privileges of the Society. He shall be eligible to hold any office, to vote on all matters submitted to the membership, to petition the Council or Executive Committee on any matter, to sponsor applicants for membership and to publish his affiliation with the Society.

Section 8. An Associate Member or Student Member shall be entitled to attend the meetings of the Society, to receive its Journal and to purchase its publications, on the same terms as an Active Member. He shall have none of the other privileges of membership and in publishing his affiliation with the Society shall clearly indicate his grade of membership.

Article IV. Code of Ethics

Section 1. Membership of any class shall be contingent upon conformance with the established principles of professional ethics.

Article V. Election, Resignation and Expulsion of Members

Section 1. The method of election to the various grades of membership shall be as set forth in the Bylaws.

Section 2. Any member in good standing may resign from the Society at any time as set forth in the Bylaws.

Section 3. Any member may for the good of the Society be suspended or expelled from the Society at any time as set forth in the Bylaws.

Article VI. Officers

Section 1. The officers of the Society shall be a President, a Vice-President a Secretary-Treasurer, and an Editor. Officers shall be elected in the manner prescribed in the Bylaws for a term of one year with the exception of the Editor, whose term shall be two years.

Section 2. Election of officers shall be by secret mail ballot. On the ballot shall be printed the nominees for each office arranged in alphabetical order.

Section 3. The Standing Committee on Nominations shall nominate, in the manner prescribed in the Bylaws, two candidates for each office to be filled. Further nominations may be made by petition as set forth in the Bylaws.

Section 4. The officers shall assume the duties of their respective offices immediately after the close of the Annual Meeting following their election.

Section 5. No officer shall be eligible for election to the same office for two consecutive terms.

Section 6. In case of a vacancy in any office, other than the President's, the Executive Committee shall select a successor to serve until the close of the annual meeting following this appointment.

Article VII. Duties of Officers

Section 1. The President shall be the presiding officer at all the meetings of the Society, shall take cognizance of the acts of the Society and of its officers, shall appoint such Standing Committees and special committees as are required for the purposes of the Society, and shall delegate members to represent the Society. He may, at his option, serve on, and may be chairman of, any committee. He shall prepare an address to be given before the members of the Society at the Annual Meeting.

Section 2. The Vice-President shall assume the office of President in case of a vacancy from any cause in that office and shall assume the duties of President in case of the absence or disability of the latter. He shall also be responsible for all National Meetings of the Society.

Section 3. The Secretary-Treasurer shall assume the duties of the President in case of the absence of both the President and Vice-President. He shall have charge of the financial affairs of the Society and shall annually submit reports as Secretary-Treasurer covering the fiscal year, which he shall arrange to have published in the next regular issue of the Journal of the Society. Under the direction of the Council, he shall arrange for the receipt and disbursal of all Society funds. He shall cause an audit to be prepared annually by a public accountant at the expense of the Society. He shall give a bond, and shall cause to be bonded, all employees to whom authority may be delegated to handle Society funds. The amount of such bonds shall be set by the Council and the expense shall be borne by the Society.

Section 4. The Editor shall be in charge of the editorial business, shall submit an annual report of such business, shall have authority to solicit papers and material for the regular Society publication and for special publications, and may accept or reject material offered for publication. He may appoint associate, regional, and special editors.

Article VIII. Council

Section 1. The Council of the Society shall consist of the officers, the Past President, the Past Prior President, and all elected District Representatives.

Section 2. The Council shall be the governing body of the Society and subject to the provisions of the Constitution and Bylaws shall have full control and management of the affairs and funds of the Society.

Section 3. A joint meeting of the outgoing and incoming Councils shall be held at the call and under the Chairmanship of the newly elected President during or within seven days after the Annual Meeting of the Society. At this joint meeting the Councils shall hear reports from all Officers and Committees and review the activities of the Society for the past year. With the advice of the outgoing Council, the incoming Council shall conduct any necessary business and issue instructions or recommendations to any officer or committee, subject to the provisions of the Constitution and Bylaws. All committee chairmen shall attend this meeting, but, as Chairmen, shall have no vote.

Section 4. At the call of the President or a majority of the Council members, and after written notice to all Council members, the Council may meet at any time.

Section 5. A quorum at any meeting of the Council shall consist of six Council members.

Section 6. Unless otherwise provided by the Constitution, all actions by the Council shall require a majority vote of the members present.

Article IX. Executive Committee

Section 1. The Executive Committee shall consist of the President, the Vice-President, the Secretary-Treasurer, the Editor, and the Past President.

Section 2. When the Council is not in session the Executive Committee shall have full authority, subject only to prior instructions by the Council, to exercise all powers of the Council.

Section 3. All actions of the Executive Committee shall require a majority vote of all members of the Committee.

Section 4. The Executive Committee may vote on any matter either by mail or in person.

Article X. Meetings

Section 1. The Society shall hold at least one meeting of the members each year, this meeting to be known as the Annual Meeting. One session of this meeting shall be a Business Meeting, at which reports of the Officers and Committees shall be read and the result of the mail ballot for officers announced.

Section 2. The Annual Meeting shall be held at a time and place designated by the Executive Committee.

Section 3. Additional meetings of the Society may be called by the Executive Committee.

Article XI. Local Sections

Section 1. Local sections, consisting of members of the Society and other persons engaged in geophysics or a related field residing within an appropriate distance of a central point, may be organized as provided in the Bylaws.

Section 2. Each local section shall assist in carrying out the objectives of the Society within the territory assigned to the section by the Council.

Section 3. Each local section shall have one district representative if among its members there are less than seventy-five Honorary Members and Active members of the Society in good standing, two district representatives if more than seventy-five and less than one hundred fifty, or three district representatives if more than one hundred fifty.

Section 4. The district representatives shall be elected from among the Honorary Members and Active Members of the Society in good standing for terms stated and in the manner prescribed in the Bylaws and shall not be eligible for two consecutive terms.

Article XII. Districts

Section 1. The Council shall divide the area of the continental United States, not assigned to local sections, into not more than seven districts. Council may designate districts outside the area of the continental United States.

Section 2. Each district shall have for each seventy-five Active members of the Society, who are not members of a local section, one district representative, who shall be appointed by the President, for a term of one year expiring at the close of the Annual Meeting.

Article XIII. Affiliated Societies

Section 1. The Council may arrange for affiliation of the Society with any duly organized groups or societies.

Section 2. The terms of affiliation must provide that the Society shall have the right to dissolve such affiliation at any time, subject only to the payment of any sums it may legally owe the affiliated group or society.

Article XIV. Committees

Section 1. In addition to the Executive Committee, there shall be appointed Standing Committees to further the purposes of the Society.

Section 2. The duties of the Standing Committees and the method of their appointment shall be in accordance with the Bylaws.

Section 3. The President may at any time appoint Special Committees for such purposes as he may deem fit.

Section 4. The terms of all Special Committees shall expire at the close of the Annual Meeting following their appointment.

Article XV. Business Manager

Section 1. The Council may employ a Business Manager for the Society and pay him such salary and other compensations from the Society's funds as they deem advisable.

Section 2. The Business Manager shall provide a bond appropriate in amount, the cost to be borne by the Society.

Section 3. The Business Manager shall, under the supervision of the Secretary-Treasurer, perform such duties as the Council may assign him.

Section 4. The Council may discharge the Business Manager at any time.

Article XVI. Review by Members

Section 1. All acts of the Officers, Council, and Committees of the Society shall be subject to review by the members.

Section 2. Proposals to change any decision, policy or procedure of any Officer, the Council, or any Committee shall be submitted in writing to the President and signed by at least twenty-five Honorary and Active Members in good standing.

Section 3. Upon receipt of such a petition with a sufficient number of valid signatures, the President shall advise the Council and the Officer or Committee involved.

Section 4. Should the Officer or Committee involved be unwilling to comply with the petition, it, together with a discussion by the proposer and the Officer or Committee involved, shall be published in the next issue of the Society's Journal.

Section 5. Within thirty days after publication in the Journal, the petition shall be submitted to the membership by mail ballot by the President. A majority of the ballots returned within thirty days after being mailed by the President shall be decisive. Should the vote favor the petition, it shall be complied with, within the limitations imposed by the Constitution and Bylaws, as promptly as practicable.

Article XVII. Bylaws

Section 1. The Council shall make such Bylaws not in conflict with the Constitution, as it may deem necessary for the proper government of the Society. The Council may amend the Bylaws at the annual joint meeting by an affirmative vote of two-thirds of the members of the incoming Council present. All proposed amendments must, however, be published in the Society's Journal before being submitted to the Council.

Article XVIII. Amendments to the Constitution

Section 1. Amendments to this Constitution may be proposed by any ten members of the Society, by any Officer of the Society, or by a Constitutional Committee appointed by the President.

Section 2. Any proposed amendment shall be submitted to the President in time for publication in the Society's Journal prior to the Annual Meeting.

Section 3. At the annual joint meeting of the Council, all proposed amendments received since the previous annual meeting, shall be considered. Those receiving approval from a majority of the members of the incoming Council present shall be submitted by mail ballot, arranged by the Secretary Treasurer, to the entire membership of the Society within sixty days. If a majority of the ballots returned within sixty days of their mailing favor the proposed amendment, it shall become effective at the expiration of this sixty days. All amendments shall be reported in the Society's Journal.

BYLAWS

Article I. Publications
Article II. Election of Honorary Members
Article III. Election of Active, Associate and Student Members
Article IV. Dues
Article V. Resignation of Members
Article VI. Expulsion of Members
Article VII. Election of Officers
Article VIII. Local Sections
Article IX. Finances of Local Sections
Article X. Standing Committees

BYLAWS

Article I. Publications

Section 1. The Society shall publish a Journal entitled *Geophysics*.

Section 2. The Journal shall be published at intervals designated by the Executive Committee.

Section 3. All reports to the Society by its officers and committees shall be published in the Journal. All members of the Society shall be presumed to have due notice of all Society matters published in the Journal. Each issue shall contain a membership list of all Standing and Special Committees.

Section 4. Original papers, reviews, abstracts, notes or letters containing information deemed by the Editor to be of interest to the members of the Society shall be published in the Journal. The Editor shall be the sole judge of whether such material is to be published.

Section 5. The subscription rate of the Journal shall be $6.00 ($6.50 foreign) per year to nonmembers and $3.00 per year to members. The first $3.00 of the annual dues of each due paying member shall be set aside for the payment of his subscription to the Journal. Members of affiliated Societies shall be entitled to receive the Journal upon payment of a fee equivalent to the dues charged to an associate member.

Section 6. The Council may at its annual joint meeting authorize the printing of special publications to be financed and distributed in a manner approved by the Council.

Article II. Election of Honorary Members

Section 1. The Standing Committee on Honors and Awards may submit to the President ninety days before the Annual Meeting the names of any person or persons they deem eligible to election as an Honorary Member. Their report shall explain the basis of their recommendation.

SECTION 2. The President shall submit copies of any such reports to all members of the Council not less than sixty days before the Annual Meeting.

SECTION 3. The Council members shall consider all such reports and vote by mail thirty days before the Annual Meeting. Unanimous action by those voting shall be required to elect any person as an Honorary Member.

ARTICLE III. ELECTION TO ACTIVE, ASSOCIATE AND STUDENT MEMBERSHIP

SECTION 1. An applicant for election to Active, Associate or Student Membership shall submit to the Business Manager of the Society an application setting forth in detail his education and experience. The application shall list the names and present addresses of persons who can verify the statements given therein. It shall list not less than three Active Members or Honorary Members of the Society, in good standing, who are personally acquainted with the training or experience of the applicant. This application shall be open to inspection at any time.

SECTION 2. The Executive Committee may waive the requirement of references from members of the Society for geographical or other reasons, if the applicant is otherwise eligible and furnishes other satisfactory references.

SECTION 3. The Business Manager shall write to all references for verification of the applicant's statements. All replies from references shall be considered confidential and shall not be disclosed except to the Executive Committee, without the references' prior written consent.

SECTION 4. The Business Manager, upon receipt of the replies from all references, shall submit to the Executive Committee the application and the replies from the references.

SECTION 5. Should the Executive Committee unanimously approve and sign the application, the applicant's name shall be published in the next regular issue of the Society's Journal for approval by the membership at large. If no objection to his election is received by the President within thirty days after this publication, he shall be pronounced elected. The Business Manager will notify the applicant. In the case of applicants for Student Membership publication is not required. The student member shall be pronounced elected when approved by the Secretary-Treasurer.

SECTION 6. An applicant for membership, upon being notified in writing of his election, shall pay full dues for the current year and upon making payment shall receive a membership card and the regular Society publications for the year of entrance. Unless payment of dues is made within thirty days by those living within the continental United States and within ninety days by those living elsewhere, the Executive Committee may rescind the election of the applicant.

SECTION 7. An Associate or Student Member may seek transfer to Active Membership by supplying added information to show that he has become eligible to election to Active Membership. The transfer shall be handled in the same manner as election to Active Membership. The Standing Committee on Membership may of its own initiative secure the necessary added information and submit it to the Executive Committee.

ARTICLE IV. DUES

SECTION 1. Honorary members shall not be required to pay dues and shall receive the Journal and other publications without charge.

SECTION 2. The annual dues of an Active or Associate Member of the Society shall be five dollars ($5.00), which includes the cost of one subscription to the Society's Journal.

SECTION 3. The annual dues of a Student Member of the Society shall be three dollars ($3.00), which includes the cost of one subscription to the Society's Journal.

SECTION 4. Annual dues shall be payable in advance on January 1 of the calendar year. A bill shall be mailed to each Active, Associate or Student Member before that date, stating the amount of annual dues and the penalty for default. The Society's Journal shall be withheld from members pending payment of dues, and Active Members failing to pay by ten days prior to the Annual Meeting shall have their votes in the annual mail ballot disqualified. Members in arrears shall lose all privileges of membership until such arrears are met.

Article V. Resignation of Members

Section 1. Any member of the Society may resign at any time. Such resignation shall be submitted in writing to the Council.

Section 2. Any member who resigns under the provisions of Section 1 of this Article ceases to have any rights in the Society and ceases to incur further indebtedness to the Society.

Section 3. Any person who has ceased to be a member under Section 1 of this Article may be reinstated by unanimous vote of the Executive Committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member of the Society.

Article VI. Expulsion of Members

Section 1. Any member more than two years in arrears shall be dropped from the Society by the Executive Committee.

Section 2. Any member who is dropped under the provisions of Section 1 of this Article ceases to have any rights in the Society and ceases to incur further indebtedness to the Society.

Section 3. Any person who has ceased to be a member under Section 1 of this Article may be reinstated by unanimous vote of the Executive Committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member of the Society.

Section 4. Any member who, after being granted a hearing by the Executive Committee, shall be found guilty of a violation of the established principles of professional ethics, or shall be found guilty of having made a false or misleading statement in his application for membership in the Society, shall be asked to resign from the Society by unanimous vote of the Executive Committee. The decision of the Executive Committee in all matters pertaining to the interpretation and execution of the provisions of this section shall be final.

Article VII. Election of Officers

Section 1. The Standing Committee on Nominations shall consist of the President, the Past President, and the Prior Past President.

Section 2. The Standing Committee on Nominations shall nominate two or more candidates for each office to be filled. They must secure the consent of all candidates nominated.

Section 3. The Standing Committee on Nominations must submit their ticket to the President in time for publication in the October issue of the Society's Journal.

Section 4. For six weeks after the mailing date of the October issue of the Society's Journal, nominations in writing, signed by at least twenty Honorary Members or Active Members in good standing and accompanied by the written consent of the candidate, may be submitted to the President.

Section 5. At the expiration of the aforesaid six weeks period, the Business Manager will prepare and mail to each member, eligible to vote, a ballot listing all candidates properly nominated for each office. The candidates shall be listed alphabetically. With each ballot, the Business Manager shall send an official envelope having the member's name typed on the back.

Section 6. Each member voting shall cast one vote for each officer and shall return his ballot to the Business Manager in the official envelope carrying on the outside the written signature of the member submitting the ballot. Only ballots so prepared by members in good standing, and received by the Business Manager at his officially recognized address not later than ten days prior to the Annual Meeting shall be valid. The Business Manager shall indicate which ballots are valid and shall deliver the ballots unopened to the Standing Committee on Nominations for counting. The Standing Committee on Nominations shall personally supervise the counting of the ballots prior to the Annual Business Meeting. The candidates receiving the greatest number of valid votes cast for an office shall be declared elected to that office. In case of a tie, the Standing Committee on Nominations shall decide by a secret vote which of the candidates shall be elected.

Article VIII. Local Sections

Section 1. Upon petition of twenty members in good standing residing within an appropriate distance of a central point, the Council may authorize the formation of a Local Section and assign a specific territory to the Local Section. The Council may decline to authorize the formation of a Local Section when in its judgment such an organization would not be compatible with the interests of the Society.

Section 2. In the organizing meeting of the Section, all members of the Society residing in the territory assigned by the Council to the Section shall be eligible to vote.

Section 3. The Section shall be known as "The (name of place) Section of the Society of Exploration Geophysicists."

Section 4. The principal work of a Section shall be the holding of regular meetings for the presentation and discussion of papers of interest to its members.

Section 5. The Section shall adopt Bylaws which must be approved by the Council of the Society and shall be consistent with the Constitution and Bylaws of the Society.

Section 6. The election of District Representatives by the Local Sections shall be by secret ballot. The term of office of a District Representative shall be two years; however, if the Section is entitled to more than one Representative, one of the Representatives elected at the establishment of the Section or added as the result of subsequent growth of the Section, shall be elected for a one year term if this is necessary to prevent the terms of all District Representatives from expiring simultaneously.

Section 7. District Representatives shall be elected at least three weeks prior to the Annual Meeting of the Society and shall take office at the close of the Annual Meeting.

Section 8. The Secretary of the Local Section shall submit to the Secretary-Treasurer of the Society a report of each meeting of the Local Section or its governing board within two weeks after the meeting. He shall submit to the Secretary-Treasurer of the Society the names of all officers and committee members within two weeks after their election or appointment.

Section 9. Any Local Section which for two consecutive years has among its membership fewer than twenty members in good standing of the Society shall automatically be dissolved by the Council at its annual joint meeting. The Council may at any time dissolve any Local Section for reasons it deems good and sufficient.

Article IX. Finances of Local Sections

Section 1. The Society will pay the necessary operating expenses of a Local Section up to the sum of the following amounts: (a) $100.00 per year; (b) $50.00 per meeting up to four meetings per year; (c) $0.50 per member of the Society.

Section 2. The Treasurer of the Local Section shall forward, from time to time, his application for such portions of the sum provided in Section 1 as may be needed to the Secretary-Treasurer of the Society, who will arrange for the issuance of a check for the requested amount to the Treasurer of the Local Section.

Section 3. Prior to the Annual Meeting, the Treasurer of each Local Section shall transmit to the Secretary-Treasurer of the Society, for approval by the Council, an itemized statement of the expenditure of the funds received from the Society during the preceding calendar year.

Section 4. Allocations to a Local Section for the year in which it is established shall be in proportion to the fraction of the calendar year remaining.

Section 5. The Local Section may levy dues or raise funds in any other manner, subject to the approval of the Council. Payment of local dues shall, however, not be a prerequisite to participation in any activity financed wholly or in part with funds received from the Society.

Article X. Standing Committees

Section 1. The Society shall have the following Standing Committees: (a) Standing Committee on Nominations; (b) Standing Committee on Membership; (c) Standing Committee on Honors and

Awards; (d) Standing Committee on Publications; (e) Standing Committee on Program and Arrangements; (f) Standing Committee on Education; and (g) Standing Committee on Student Membership.

SECTION 2. Each Standing Committee shall have a chairman, appointed by the President unless otherwise specified in these Bylaws. The Chairman shall submit a report to the President of the Society at such intervals as the Chairman may deem advisable but at least quarterly. He shall submit to the Council at its annual joint meeting a report covering the activities of the Committee since the previous annual meeting.

SECTION 3. The Standing Committee on Nominations shall consist of the President who shall be chairman, the Past President, and the Past Prior President. Its duties shall be to nominate candidates for officers, to supervise counting the ballots and to declare the election of the officers as prescribed in Article VII of these Bylaws.

SECTION 4. The Standing Committee on Membership shall consist of three active members appointed for a period of one year by the President immediately following the Annual Meeting. One of the members appointed shall have been a member the preceding year. The Committee shall prescribe the manner of soliciting applicants for membership.

SECTION 5. The Standing Committee on Honors and Awards shall consist of five active members, none of whom shall have been members of the Society less than five years. The senior member of the Committee shall retire after the Annual Meeting. Vacancies shall be filled by the President. The Committee shall recommend candidates for election to Honorary Membership to the Council. The Committee shall recommend to the Council the establishment of Honors and Awards and shall recommend candidates for all established Honors and Awards of the Society to the Council.

SECTION 6. The Standing Committee on Publications shall consist of five active members who shall serve a two year term concurrent with the Editor and who shall be appointed by the Editor. The Committee shall have the duty of advising and assisting the Editor. The Editor shall appoint the Chairman of this Committee.

SECTION 7. The Standing Committee on Program and Arrangements shall consist of the Local Representatives plus three to ten additional active members or fellows appointed for a term of one year by the Vice-President, who shall be Chairman. The names of the members of the Committee shall be published in the July issue of the Society's Journal. The Committee shall have the duty of assisting the Vice-President in arranging and holding the Annual Meeting.

SECTION 8. The Standing Committee on Education shall consist of five active members appointed for one year by the President. The Committee shall promote effective geophysical education.

SECTION 9. The Standing Committee on Student Membership shall consist of five active members appointed for one year by the President. The Committee shall encourage the interest of students in geophysics and the Society.

SOCIETY OF EXPLORATION GEOPHYSICISTS

MEMBERSHIP LIST (MARCH 1, 1949)

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Buffum, C. Emery
Cady, Francis H.
Campbell, Francis F.
Cash, Harvey, Jr.
Christie, Norman J.
Christy, Robert F.
Clayton, Neal
Cline, A. F.
Cochrane, David W.
Coffin, R. Clare
Connell, Joe E.
Cooley, E. H.
Cooper, Jack R.
Cornett, J. R.
Coryn, F. R.
Crump, William W.
Crumrine, Kenneth C.
Cunningham, William J.
Damon, Everett F.
Davenport, Robert
Davis, D. R.
Day, Charles E.
Dimmick, Opie
Doll, W. R.
Duller, Charles E.
Dunagan, Lillard C.
Dyk, Karl
Dzwons, George S.
Edmonson, Carl L.
Egan, Daniel G.
Etnyre, John B.
Eisler, Joseph D.
Engle, A. Wendell
Erdahl, William M.
Evans, Cavid Lecount
Evans, Julian F.
Fearon, R. E.
Ferguson, John L.
Ferris, Craig
Finn, Robert S.
Foster, G. A.
Franklin, John V.
Friendly, Jack L.
Frossard, Robert L.,
Fruehling, S. W.
Garner, J. P.
Garpner, Erik U.
Gemmer, R. W.
Gilkison, Don
Gilliam, J. T.
Gilmore, John A.
Gilmore, Robert J.
Gilmour, Andrew
Giltinan, G. M.
Giulio, Stanley E.
Grimm, G. A.
Handley, E. J.
Harbach, Robert G.
Harlow, Robert O.
Harlton, Bruce H.
Harper, James C.
Harris, D. B.
Hartline, Ralph E.
Harvey, Castle J. C.
Hawes, Julian K.
Hawkins, J. E.
Hawpe, Franz M.
Hays, Clyde L.
Hazelrigg, James B.
Heap, W. O.
Heim, Jean W.
Hidy, John H.
Hill, Sarah Ann
Hoffman, John C.
Hopkins, James S.
House, A. Maxwell
Hovi, Theodore W.
Hurry, Clare N.
Ingle, Gerald W.
Innes, Arland I.
Jackson, Judson G.
Jackson, Kenneth
James, Ralph F.
Jameson, Chet H. Jr.
Jeffers, Paul H.
Jewell, David F. Jr.
Jones, Charles E. Jr.
Jones, John Paul
Jones, V. L.
Kendall, G. D.
Kendall, R. C.
Kennett, H. E.
Keselik, Joseph
Kezeler, J. L.
Kimball, Jack E.
Kittredge, F. R.
Knowles, J. G.
Koeppel, B. W.
Kundert, Karl H.
Lambert, G. D.
Lambkin, Woodrow W.
Lang, Harold M.
Larguier, Leonard J.
Lash, Charles C.
Lawrence, K. M.
Laws, J. O.
Leas, Ruth R.
Lynn, Ralph D.
Lyons, Paul L.
Mace, H. G.
Manhart, T. A.
Maras, Robert G. Jr.
Martin, Dick
Martin, Donald R.
Mathieson, Raymond L.

Maxey, J. R.
Mayes, Tom D.
McAlister, C. H.
McClure, C. E.
McCollum, E. V.
McCracken, Guy I.
McNatt, E. M.
Mehringer, A. P.
Miller, Nash H.
Mitchell, Fielding L.
Mooney, Donald N.
Moore, Homer C.
Moore Leland E.
Moore, W. Lee
Mossman, R. W.
Nash, John M.
Newton, George R.
Novelly, Walter, O.
Oliphant, Charles W.
Owen, H. E.
Owen, John E.
Pakiser, Louis C.
Palmer, John E.
Parker, G. A.
Patterson, A. R.
Pentecost, Claude D.
Peterson, Glen
Petschek, A. P.
Pirson, Sylvain
Plumlee, Leah Frances
Poe, Herbert
Pogue, Douglas M.
Preston, B. G.
Pugh, William
Raborn, Smiley, Jr.
Rankin, C. T.
Reed, David E.
Reed, George W.
Reid, A. C.
Richardson, J. W.
Rickel, Wesley K.
Ricker, Norman
Riley, James K.
Roark, James J.
Robertson, K. A.
Robinson, William J.
Rollins, J. C.
Romberg, Marvin
Ross, C. M.
Ross, R. B.
Rupnik, John J.
Rutledge, Richard B.
Scherbatskoy, S. A.
Schoellhorn, S. William
Schultis, G. E.
Scott, C. B.
Seaman, L. O.
Sharpe, Joseph A.
Sibley, W. B.
Silverman, Daniel
Smith, Frank B.
Southgate, Tom F.
Sparks, N. R.
S. Ross, John T.
Stephens, T. V.
Stotler, Thomas C.
Strachan, Clyde G.
Swift, Gilbert
Swift, Lawrence M.
Sype, William R.
Taylor, Albert
Taylor, Garvin L.
Thayer, Jean M.
Thomas, T. J.
Thralls, H. M.
Tucker, R. H.
Van Order, Keene C.
Vernon, Jess
Von Croy, Stefan
Waldrep, W. Day
Watson, Robert J.
Weatherby, B. B.
Wells, William M.
Westby, G. H.
Widess, M. B.
Williams, P. S.
Williams, Richard
Wilson, James N.
Winn, Clayton N.
Winnek, J. R.
Woolson, John R.

Watonga
Strayhorn, Tom R.

Waurika
Levorsen, Robert I.

OREGON

Aurora
Lester, O. C. Jr.

John Day
Culp, Harold H.

PENNSYLVANIA

Bethlehem
Agocs, W. B.
Gallagher, Robert T.
Pentz, Harold H.

Bradford
Barber, R. C.

Erie
Wuenschel, Paul C.

Gibsonia
Fink, Paul O.

Langhorne
Crary, Albert P.

Norwood
Bazzoni, Charles B.

Oakmont
Doolittle, Russell C.
Smith, Douglas H.

Palmerton
McMurray, Howard V.

Philadelphia
Jensen, Homer
Meadow, Harold
Peterson, Eugene F. Jr.

Pittsburgh
Affleck, James
Allon, Michael
Backman, John E.
Bailey, Lothrop H.
Barnum, Warren R.
Barton, Edward I.
Butler, Mark D.
Cerveny, Philip F.
Cook, D. E.
Davis, David A.
Diveley, Paul R.
Eckhardt, E. A.
Elkins, Thomas A.
Gardner, Louis W.
Gealy, Wendell B.
Gunn, J. E.
Hammer, Sigmund I.
Hazen, William G.
Herron, Robert C.
Jones, R. W.
Kilborn, J. M.
Lamb, William C.
Meszaros, W. A.
Murrell, James T.
Muskat, Morris
O'Donnell, T. J.
Palmer, E. M.
Palmer, Loyal D.
Peters, L. J.
Pezdek, Victor J.
Pomeroy, R. F.
Reiser, Robert C.
Robinson, John L. Jr.
Robinson, W. Bernhard
Watson, George R.
Weber, David M.
Wert, Carl M.
Wickerham, M. D.
Wigbels, Frank B.
Wyckoff, R. D.

Ridley Park
Johnson, F. L.

State College
Bacon, Lloyal O.
Kennedy, Vance C.
May, Harold G.
Stuart, David J.

Verona
Muffly, Gary

SOUTH DAKOTA

Aberdeen
Newquist, John W.

TENNESSEE

Oak Ridge
Garrett, George A.

TEXAS

Abilene
Herr, H. K.
Van Siclen, Dewitt C.

Alvin
Beck, Ronald E.

Amarillo
Davidson, G. Bowen
Hollis, Jack L.

Moody, N. K. Jr.

Athens
Frost, Holloway H.
Heaps, Stanley

Austin
Brack, John R.
Horton, C. W.
Hughes, Darrell S.
Mims. R. Lewis
Romberg, Frederick E.
Seale, Robert L.
Thomas, Earl

Beaumont
Conklin, Glenn M.
Davis, William Warren
Divelbiss, James
Dodd, Lavon C.
Ellis, L. G.
Hagemann, Richard Frederick
Henson, Robert L.
Hollingsworth, W. E.
Koenig, Robert J.
Konz, Leo W.
McCormack, Harold R.
Millington, John W.
Richert, Bernhard E.
Waller, John A.
Williams, C. E.
Winterhalter, Alfred

Beeville
Jackson, R. S.

Bellaire
Cowles, Laurence G.
Herzog, Gerhard
Hubby, L. M.
Lee, B. D.
Pranglin, John A.
St. Germain, Raymond J.

Big Lake
Burton, Raiford H.
Bychok, Victor

Big Spring
Barnes, Chester F.

Breckenridge
Olson, Odell C.

Brownfield
Greenlee, Paul

Cisco
Reeves, James R.

Coleman
Cheney, M. G.

College Station
Weekes, Donald F.

Columbus
Etheridge, K. E.

Commerce
Wheeler, Edwin E.

Corpus Christi
Bolinger, John W.
Daugherty, C. G. Jr.
Dunbar, R. O.
Fishback, Joseph W.
Howerton, Bert P.
McCaleb, Maurice M.
Weatherby, S. P.
Zazvorka, Jerry Jr.

Dallas
Adams, H. R.
Agnich, Fred J.
Alcock, E. D.
Amis, W. H.
Andrews, Reagan H.
Appendino, John
Archer, Milton
Armstrong, Orven H.
Arnett, R. D.
Arnold, Kingsland
Autrey, D. W.
Ayres, J. Otis
Baker, M. E.
Batson, James B.
Blattner, Sanford D.
Bonebrake, Walter C.
Brannian, Ross E.
Brock, Fred A.
Broding, Robert A.
Brown H. Hallock
Burg, K. E.
Bush, James H.
Butt, Harding
Calhoun, F. F.
Campbell, E. L.
Carlberg, Charles E.
Carson, Roe W.
Cathey, John A.
Clewell, Dayton H.
Clifford, O. C. Jr.
Cloepfil, Gordon D.
Cobb, Howard L.
Collingwood, D. M.
Congdon, R. L.
Conover, George E.
Cornell, Russell B.
Cortes. H. C.
Coursey, W. Dudley
Crump, Oscar M.
Dahm, C. G.
Deer, Joe H.
DeFord, H. L.
DeGolyer, E. L.
DeJournette, R. D. Jr.
Dobyns, D. R.
Dodson, Herbert, F.
Donnally, Chester J.
Douglas, Norvel
Dugan, Albert F.
Dunlap, H. F.
Edmonston, William J.
Eichelberger, A. M. Jr.
Elston, Chris H.
Everett, R. D.
Fain, Edgar A.
Fisher, Guy W.
Fisk, Frank K.
Floyd, Roy
Foote, Lewis C.
Gaither, Jerrel
Garrett, M. M.
Geer, J. T.
Gillin, John A.
Godbey, John K.
Godell, John J.
Granberry, H. E.
Green, Cecil H.
Green, W. G.
Gsell, R. N.
Haggarty, Patrick E.
Harkey, W. J.
Harkness, T. O.
Harvey, William P.
Hawthorne, Woodrow W.
Hayes, Quinlivan
Henderson, J. B. H.
Henderson, Ross
Heroy, William B.
Heroy, William B. Jr.
Hieatt, Herbert F.
Hightower, C. H.
Hilger, Nancy M.
Hodge, P. V.
Hogg, W. B.
Holbert, Murrell
Holm, E. Richard
Holmes, O. M.
Horn, J. W.
Huey, Wallace F.
Isensee, George W.
Jennings, Bruce M. Jr.
Jones, M. P.
Johnson, Melvin C.
Jonsson, J. E.
Joplin, Don W.
Jordan, James B.
Karcher, J. C.
Kelsey, Martin C.
Kennedy, Edward P.
Kennedy, Frank H. Jr.
Kern, Jack C. Jr.
Kiesler, Ernest A.
Lester, John A.
Linwell, Martin V.
Lipson, Leonard B.
Lomax, C. J.
MacNaughton, L. W.
Macon, Curtis
McBurney, C. G.
McCain, Hugh Jr.
McCarver, Holland C.
McCready, H. J.
McDermott, Eugene
McKay, A. E.
McLoad, Kenneth W.
McManus, Jack V.
McMullin, Elbert F.
Menefee, James C.
Miller, Jeff E. Jr.
Milstein, Mark
Minton, J. P.
Mitchell, W. R.
Molinar, J. J.
Moody, Herbert

Moore, F. A.
Morgan, Charles Gill
Musgrave, Albert W.
Napier, T. S.
Nash, Paul E.
Newton, W. W.
Nugent, Roderick M.
Olson, R. W.
Owings, B. F. Jr.
Park, Noel R.
Paslay, L. C.
Paterson, Walter D.
Pellillo, M. J.
Pernell, J. H.
Perryman, J. D.
Peters, Jack W.
Pittman, C. V. A.
Porter, C. P.
Quarles, Miller Jr.
Ralph, Pierson M.
Ransone, W. R.
Reagor, Edward C.
Reeves, W. A.
Reingans, Gerald A.
Renner, Darwin S.
Rettger, Robert E.
Robinson, George W.
Robinson, Thomas E.
Rollins, J. Frank
Roper, W. B.
Rosaire, E. E.
Rose, H. W.
Russell, Dallas, L.
Rust, Carl F.
Sanford, Robert E.
Seiler, George E.
Shugart, T. R.
Smiley, W. G., Jr.
Smith, A. Horton Jr.
Smith, Randolph
Smith, Victor W.
Smithwick, H. B.
Sole, Lewis H.
Sorrels, B. J.
Spivey, Sherman R.
Steele, D. M.
Stehr, Raymond A.
Stephens, J. L.
Stulken, E. J.
Summers, Gerald C.
Swanson, Jack G.
Thomsen, Carl J.
Toomey, Eugene James
Tottenham, W. M.
Towles, Henry C. Jr.
Travis, Fred L.
Valkus, James W.
Walton, Paul L.
Walsh, T. N.
Walton, Britain Williams
Wardell, Richard H.
Warrick, Thomas R.
Waters, Kenneth H.
Weisbrich, R. A.
White, Gale
Whiting, Gertrude
Whorton, L. P.
Williams, Charles C.
Williams, Floyd J.
Wissemann, Hilmer J.
Wodrich, Frank W.
Woods, J. P.
Woolley, William C.
Yost, W. Jacque

Eastland

Giddens, O. F.

Ft. Worth

Baird, Walter D.
Campbell, David B. Jr.
Dana, Anna Manns
Dana, R. H.
Donley, John C.
Dudley, Raymond W.
Dunlap, A. D.
Fetzer, Edwin L.
Gemmill, Edward J.
Harrington, G. Jr.
Harris, Sidon
Helley, Hans H.
Hollingsworth, W. Wise
Hunzicker, A. A.
Itten, Howard
Johnson, James F.
Kendall, John M.
Kerr, V. Robert
Laneve, R. O.
Land, Ralph H.
Ledyard, Paul H.
Long, C. J.
Lovejoy, J. B.
McLemore, Ethel Ward
Morehead, Jack N.
Morris, James L.
Normand, S. R.
Sanders, C. W.
Schouten, F. H.
Suggs, M. L.
Thomsen, Erik
Van Steenberg, S. K.
Warren, Kirby J.
Wilson, John H.

Galveston

Stover, Edward B. Jr.

Garland

White, R. H.

Grapevine

Deacon, L. E.

Hamilton

Stiles, Elisabeth

Haskell

Rowe, Ural A.

Houston

Aderman, C. V.
Adler, Joseph L.
Akkerman, Richard Pete
Anderson, John F.
Andrews, W. W.
Arsenault, Charles A.
Arthur, M. A.
Austin, Jess W.
Bader, Glenn E.
Banta, H. E.
Barbisch, J. B.
Barnes, A. L.
Barry, Adelbert
Beeman, Keith R.
Beeth, Donald
Bemrose, John
Benke, M. L.
Bennett, Roy F.
Berg, G. A.
Berleth, William H.
Bertram, A. C.
Bible, John L.
Black, J. P.
Blau, L. W.
Bowsky, M. C.
Briard, Vernon E.
Briggs, Robert B.
Brooks, James A.
Broussard, C. H.
Brown, Andrew
Brown, Hart
Buckner, Guy O. Jr.
Bugbee, J. M.
Bunsen, A. W.
Burkhalter, H. L.
Burnett, A. C.
Butler, W. W.
Byers, John W.
Campbell, H. H.
Carlton, Dave P.
Carr, George W.
Carter, Ray K.
Charrin, P. J. D.
Charske, Charles J.
Child, V. E.
Clark, George B.
Clark, W. C.
Cole, R. C.
Cook, Paul C.
Copeland, R. J.
Cornelison, Boyd
Crary, Donald
Crowder, H. V.
Crowell, J. H.
Dausman, R. H.
Davis, Donald M.
Deussen, Alexander
DeWoody, D. A.
Dissler, Ernest W.
Downey, Hugh P.
Dunway, J. H.
Duty, Robert S. Jr.
Duty, W. B.
Eberts, A. G.
Eby, J. Bryan
Edmondson, J. W. E.
Farren, Paul
Feagin, Frank J.
Fennessy, W. J.
Ferguson, J. B.

Ferguson, Joe L.
Flude, J. W.
Fohs, F. Julius
Franklin, Louis
Freel, J. F.
Frosch, A.
Frowe, Eugene
Futral, John E.
Gardner, Derry H.
Garrett, Wolliam M.
Geyer, Richard A.
Gibson, William H.
Giezendanner, S. S.
Gilliland, J. R.
Goldstone, Frank
Goss, Henry V.
Grange, Donald C.
Griffin, I. M. Jr.
Griffin, W. Raymond
Guiler, Mona D.
Guyod, Hubert
Hafner, W.
Hall, T. O.
Hamil, A. B.
Hamilton, W. Brooke
Hans, Edward
Happel, Henry H.
Hardy, Hugh W.
Harkins, Curtis P.
Harkins, T. I.
Harris, John
Hart, M. M.
Haynes, C. J.
Heintz, Karl O.
Henderson, M. R.
Henquet, R.
Hermont, Alfred J.
Herrod, Richard A. Jr.
Hibbler, A. J.
Hibbler, M. E.
Hill, E. Bruce
Hilton, Richard C.
Hinson, C. C.
Hoard, J. C.
Holland, Taylor Hugh
Horvitz, Leo
Howell, Lynn G.
Hubbard, Charles L.
Hubbert, M. King
Hull, J. W.
Hutchinson, C. C.
Ivy, John S.
Jackson, G. L.
Jett, J. E.
Johnson, Frank B.
Jubran, Joseph R.
Judson, Sidney A.
Kannenstine, F. M.
Kaufman, Sidney
Kimes, Albert
Konkel, Philip M.
Kouri, Barton H.
Krause, Fred W.
Krieg, E. A. Jr.
Kriegel, H. C.
Ladner, A. L.
Lamb, George B.
LaRue, James E.
Lawhorn, O. T.
Lay, Roy L.
Lea, W. T.
Lee, W. B.
Legge, John Allan Jr.
Leonardon, E. G.
Lewis, W. B.
Livingston, E. C.
Lowe, C. R.
MacAllister, C. T.
Mace, G. M. Jr.
MacMahon, A. M.
Manes, O. B.
Mann, Ralph W.
Marr, J. D.
Martin, Sidney A. Jr.
Martyn, Phil F.
Matthews, W. A.
McCann, K. G.
McCollum, Burton
McCullagh, John Jr.
McDonnold, H. W.
McGee, John E.
McMahan J. R. Jr.
McReynolds, Gregg F.
Miller, Robert D.
Millet, M. J.
Mitchell, George D. Jr.
Montgomery, Geo. O. Jr.
Montgomery, J. C.
Morgan, Wesley, H.
Mott Smith, L. M.
Mounce, W. D.
Mower, L. K.
Neese, Urban Earl
Nettleton, L. L.
Neuman, L. J.
Newby, C. J.
Nichols, J. B.
Norris, C. G.
Nutt, W. T.
Osmond, John C. Jr.
Osterhoudt, Walter J.
Palmer, Robert Leonard
Parker, Kenneth L.
Parker, L. A.
Parker, Richard H.
Paschall, John P.
Patrick, H. G.
Pawley, Julian K.
Peacock, H. B.
Pena, Sam M.
Pluta, Joseph S.
Raines, Eli
Pollard, Jack C.
Randolph, J. R.
Ray, Robert H.
Reed, Charles F.
Reynolds, F. F.
Roberts, R. D.
Robinson, Edwin H.
Roever, William L.
Rogers, Austin S.
Rogers, L. Brann
Rogers, Revill M.
Rolshausen, F. W.
Roos, Lewis V.
Rosaire, C. G. Sr.
Rusch, Peter J.
Ruska, Walter
Rust, W. M. Jr.
Sappington, Chester
Sargent, Raymond L.
Sauls, James L.
Saville, W. G.
Schafer, Sidney
Schmidt, Henry
Schmuck, R. H.
Schofield, G. A.
Scholl, Louis A. Jr.
Schumacher, J. P.
Sears, Harold A.
Selig, A. L.
Sharp, C. Sheldon
Sheets, Martin M.
Sherar, E. S.
Sherar, Stuart
Shettle, George O.
Shimek, E. J.
Shore, Harold F.
Sims, Sam E.
Slotnick, M. M.
Smith, A. E.
Smith, A. L.
Smith, Fred A.
Smith, H. C.
Smith, J. Angelo
Smith, Noyes D.
Smith, Warren H.
Snedden, L. B.
Somers, George B.
Speckels, Arthur W.
Sprague, Robert L.
Starr, A. G.
Steele, W. E. Jr.
Stewart, S. B.
Stockton, Frank Jr.
Stone, George B.
Stratton, Everett F.
Swartz, Charles A.
Sweet, R. C.
Taylor, Josiah
Taylor, W. Harlan
Terry, Melvin C.
Terry, Russell D.
Thompson, K. C.
Thompson, R. P.
Tucker, Robert L.
Urban, L. M.
Van Auken, John A.
Van Melle, F. A.
Vreugde, L. M. H.
Wallace, C. R.
Wallace, Frank R.

Watson, Robert Eugene
Watt, J. S.
Weatherburn, K. R.
Weaver, Paul
Weeth, Charles A.
Weingartner, R. A.
Whaley, William J. Jr.
White, Stanley A.
Whitsitt, C. D.
Wilber, Roscoe C.
Williamson, Lonnie C. Jr.
Yates, Cal
Wingett, R. O.
Winter, A. B.
Winter, George W.
Wolf, Alexander
Woods, Archie G.
Worden, Sam
Yeates, F. L.
Yokubaitis, A. C.
Zagst, Edward F.
Zavoico, Basil B.
Zimmerman, C. C.
Zirbel, N. N.

Huntsville
Hurt, W. B.

Irving
Horn, Russell E.

Jacksboro
Capp, J. T.

Kingsville
Porter, Hugh

Lamesa
Huff, Allan L.
Kerbow, R. B.
Pearce, Warren N.

Lamposas
Watts, Evan

Levelland
Heard, James R.
Sandusky, Paul M.

Liberty
Rupert, James W. Jr.

Lockhart
Notley, W. E.

Lubbock
Conant, E. E.
Epperson, R. S.
Feather, Virgil G.
Klaus, Hellmut
Morrison, M. S.
Page, C. Newton
Smith, C. C.
Unger, E. E.

McAllen
Harris, B. A.
Jett, Glendon D.

Midland
Arick, M. B.
Bradley, H. W.
Breedlove, Ruth
Fischer, Leon
Forward, Fred
Gibson, George R.
Gibson, M. O.
Homan, W. L.
Hubner, B. G. Jr.
Jackson, O. B.
Jasper, Walter E.
Long, G. J.
Mahannah, Rulon S.
Martin, G. W.
McKinsey, M. H.
Park, Lee B.
St. Clair, D. W.
Shock, Lorenz I.
Swords, Henry L.
Uhrig, Leonard F.
Warren, R. P.
Winter, Niles B.

Miller Grove
Gore, Robert F.

Mt. Pleasant
Brown, E. E.

Odessa
Davis, L. A.

Ozona
Scott, D. L.
Voelker, H. L.

Palacios
Johnson, W. D.
Sisson, H. H.

Pampa
Gallie, J. F.

Pecos
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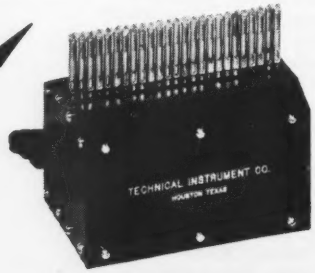

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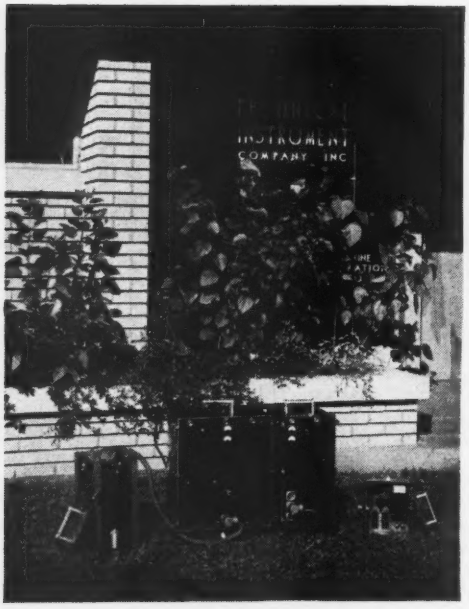

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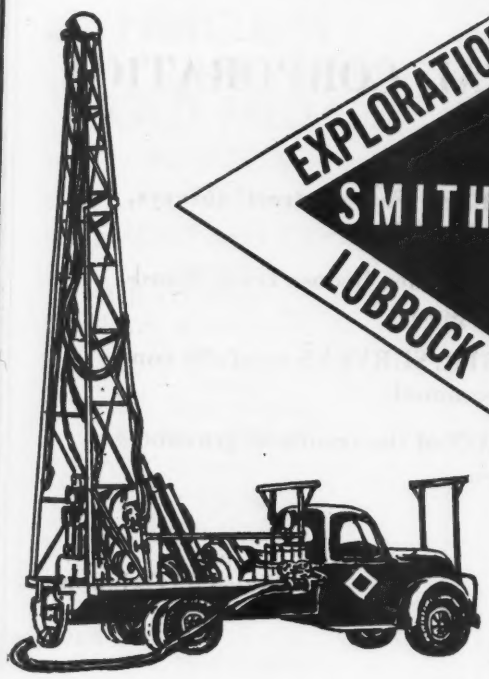

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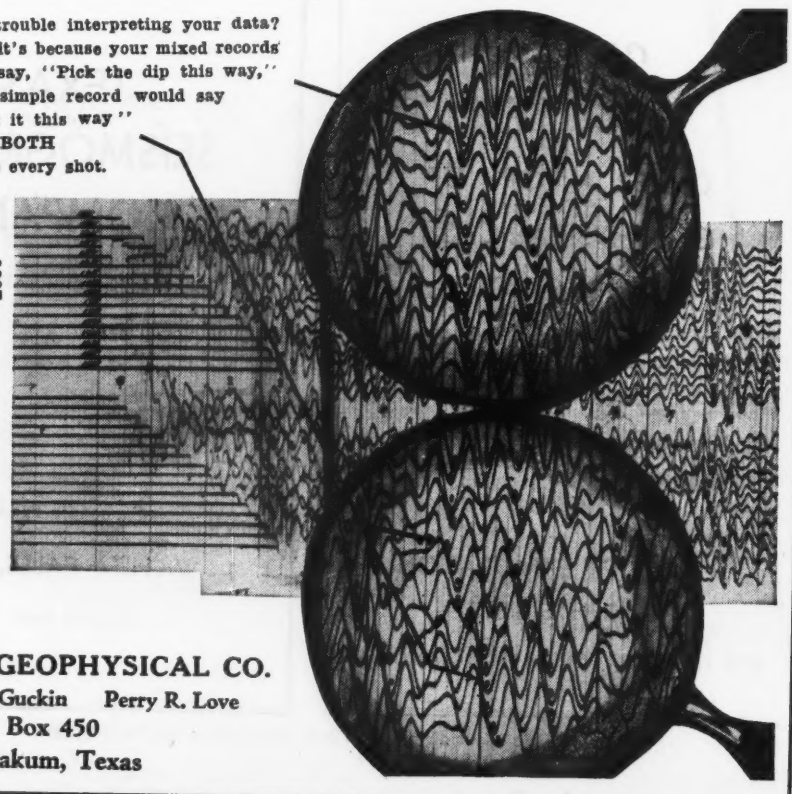

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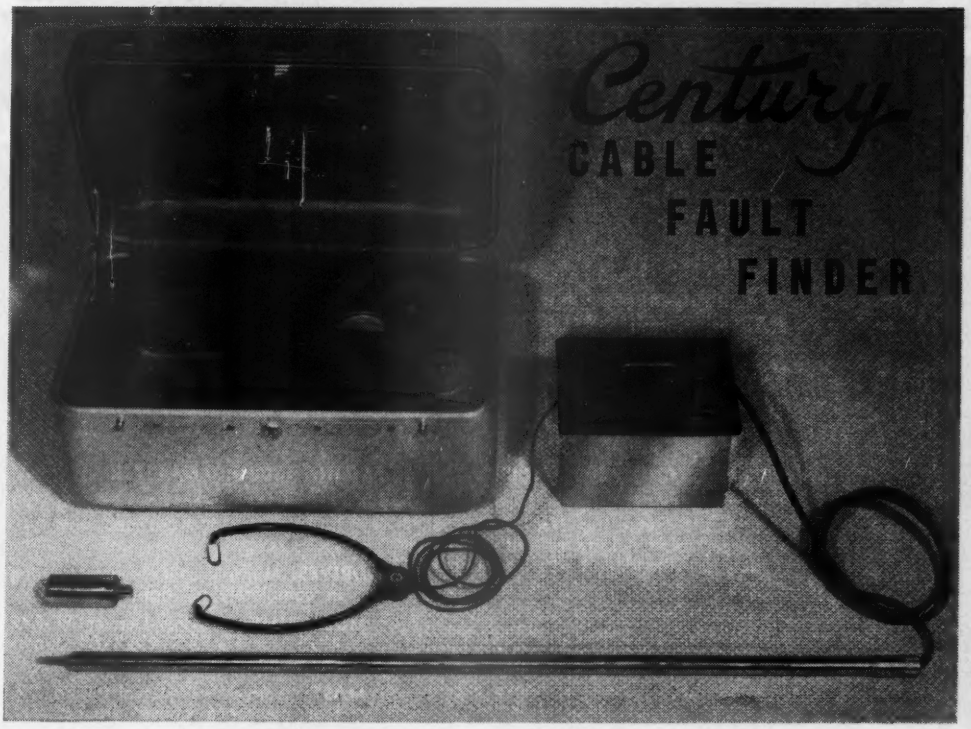

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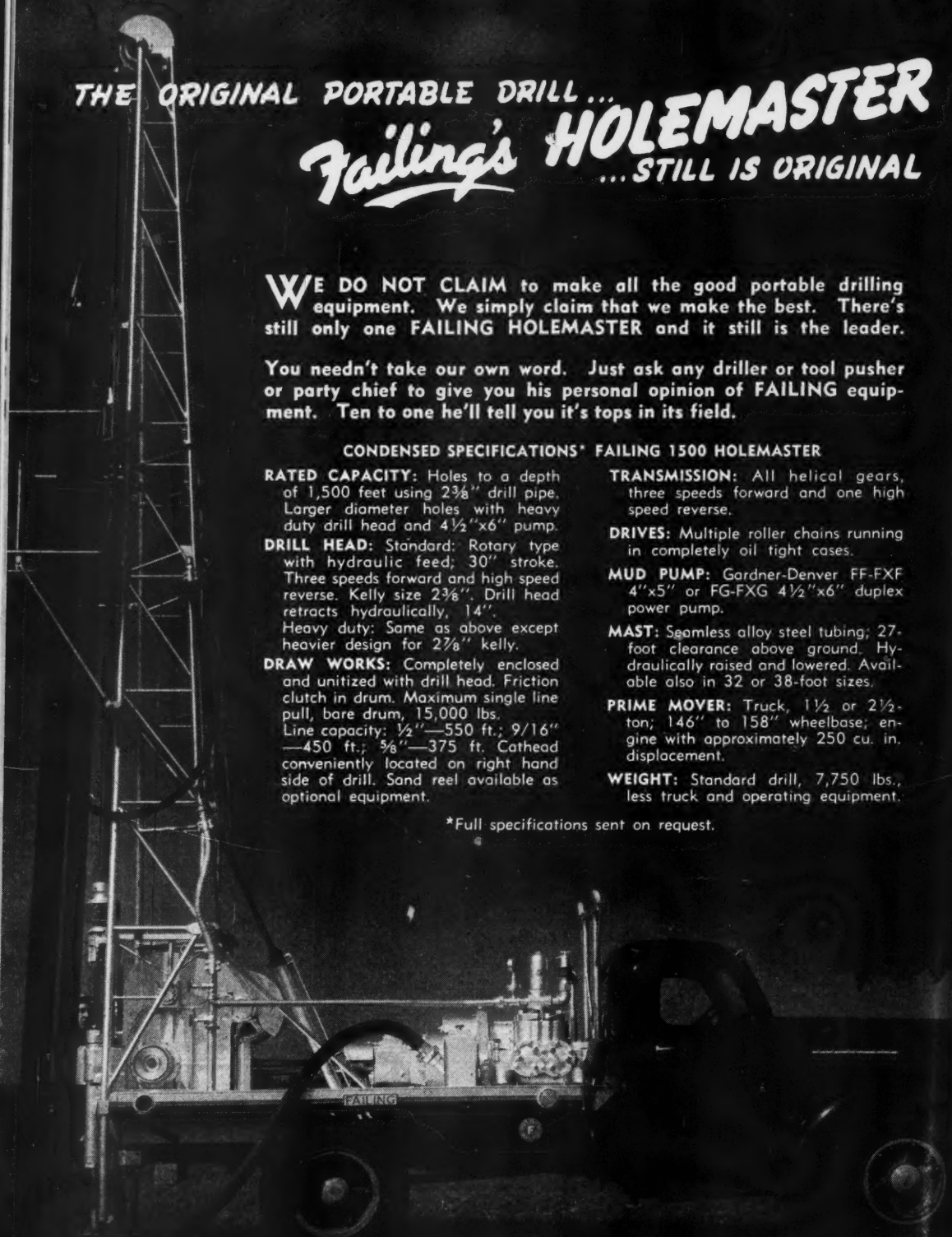

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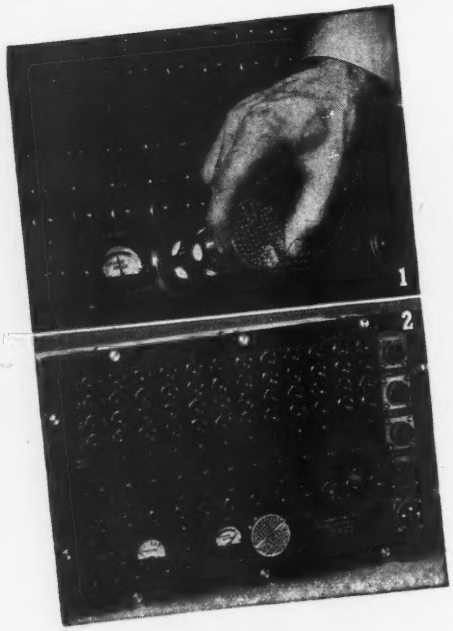

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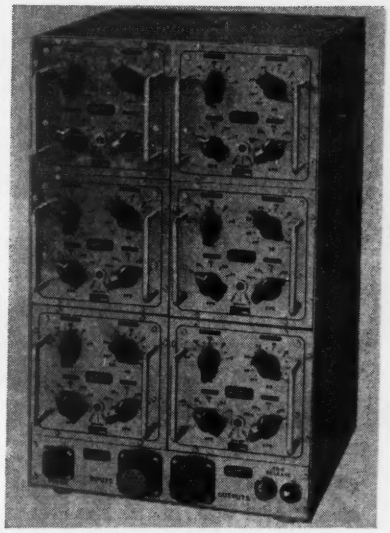
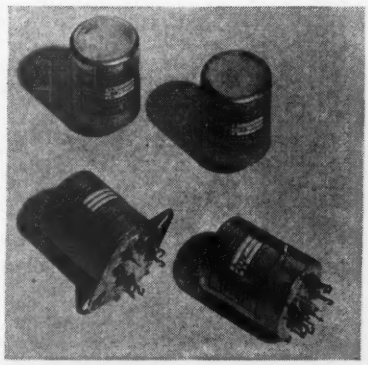
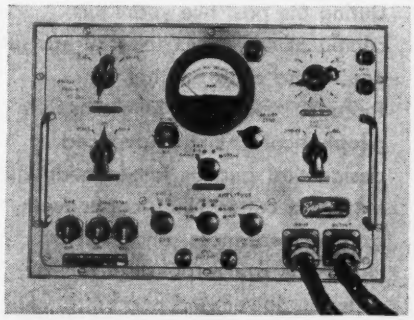


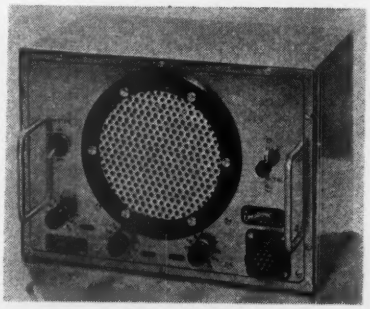
Series 4100B Amplifiers mounted in Series 4106 Case.



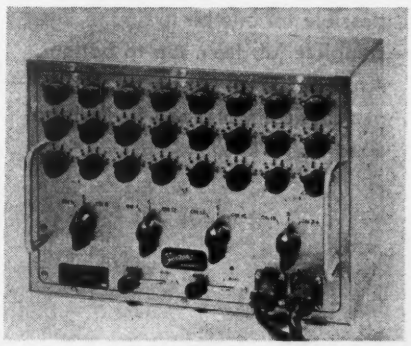
LEFT. Geotronic Exploro-Formers—transformers and inductances, compact and moisture-proof.



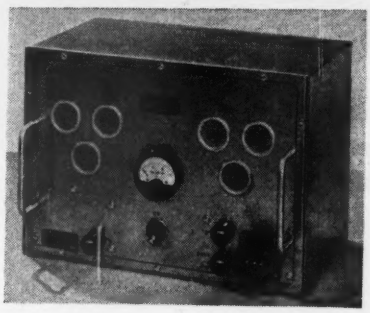
RIGHT. Input Switch and Test Unit. Accommodates up to 24 channels.



LEFT. Observer's Communicator handles time break, up hole and voice signals normally used in shooting.



RIGHT. Output Mix Unit—half and half mix between adjacent channels.



LEFT. Power Supply Unit, Model B—filtered and regulated A to B converter.

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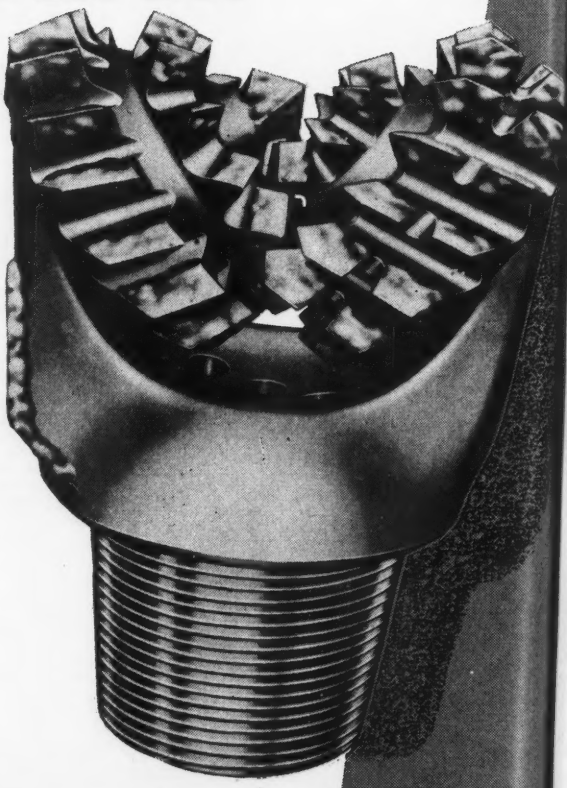

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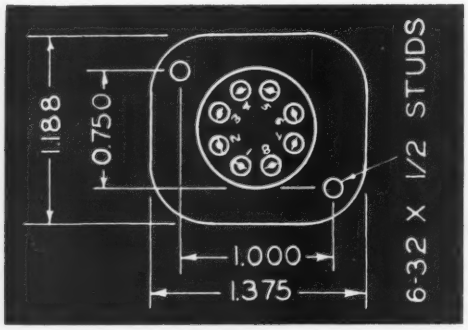

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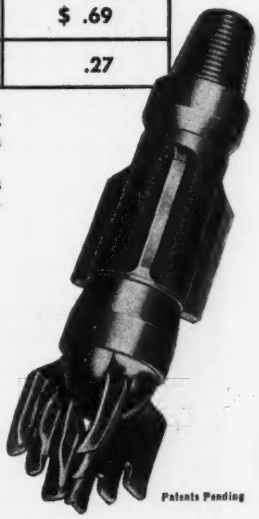

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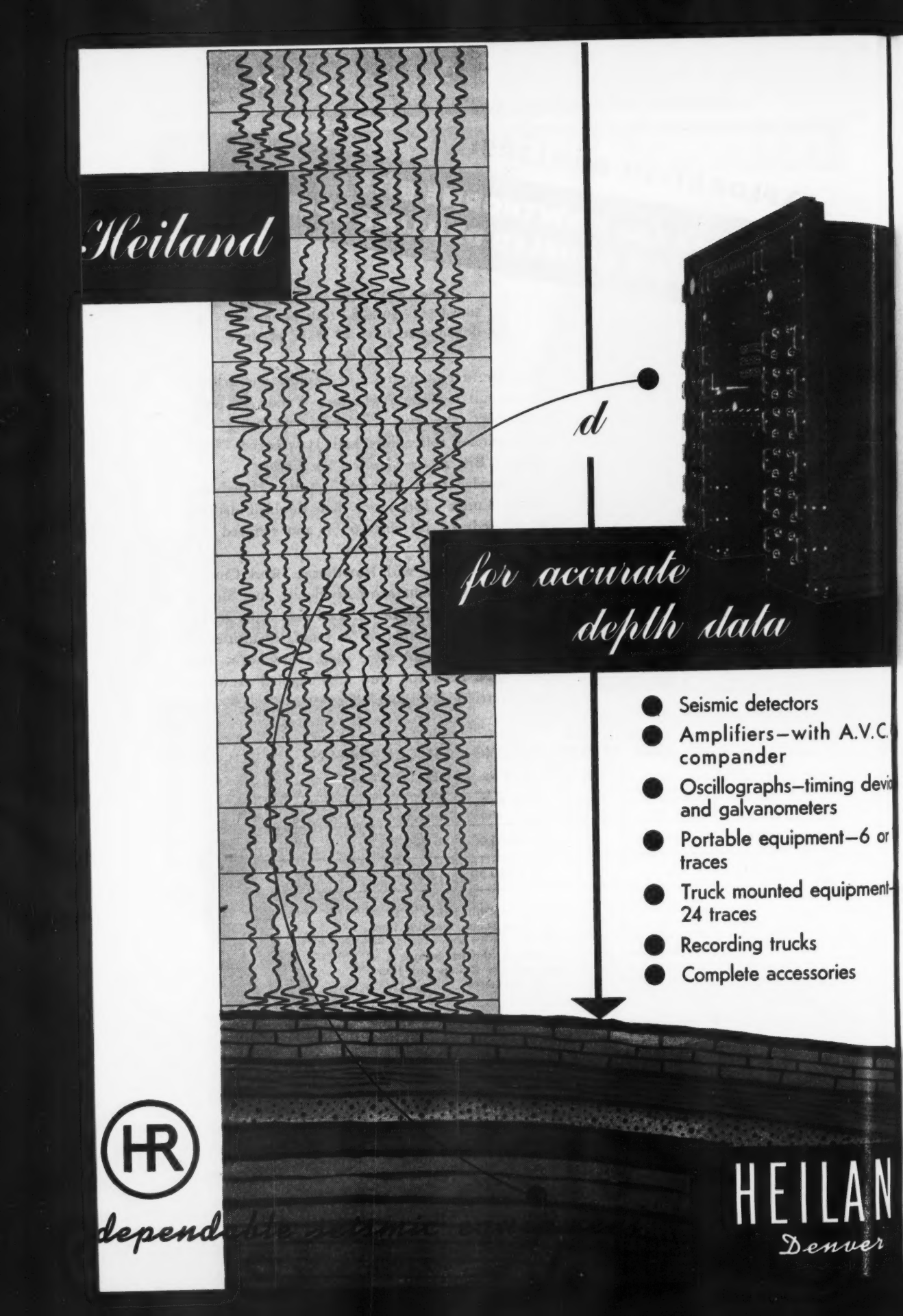
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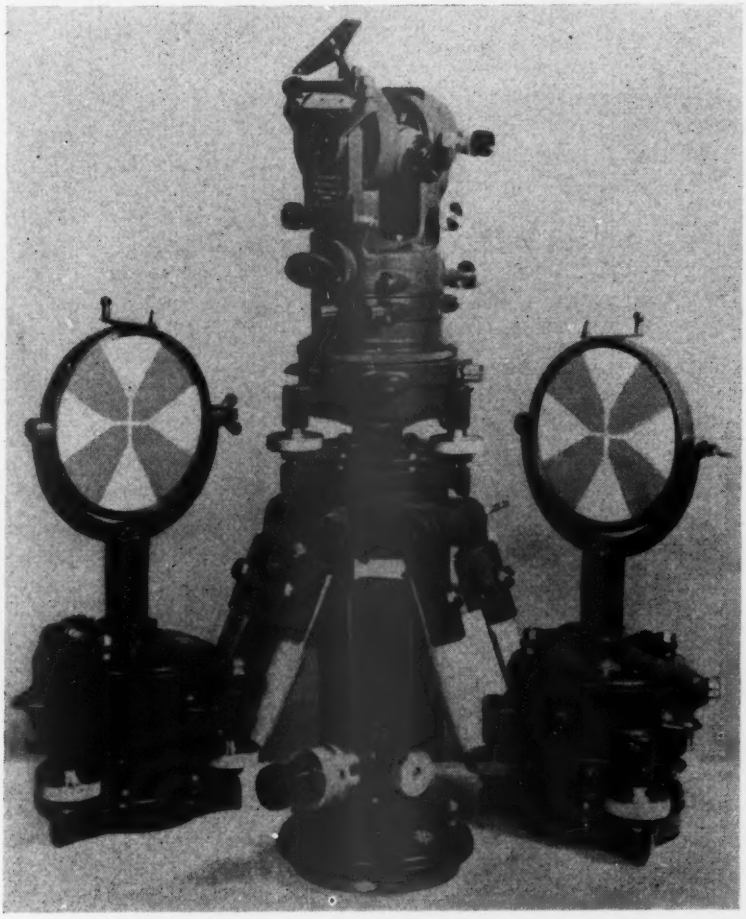

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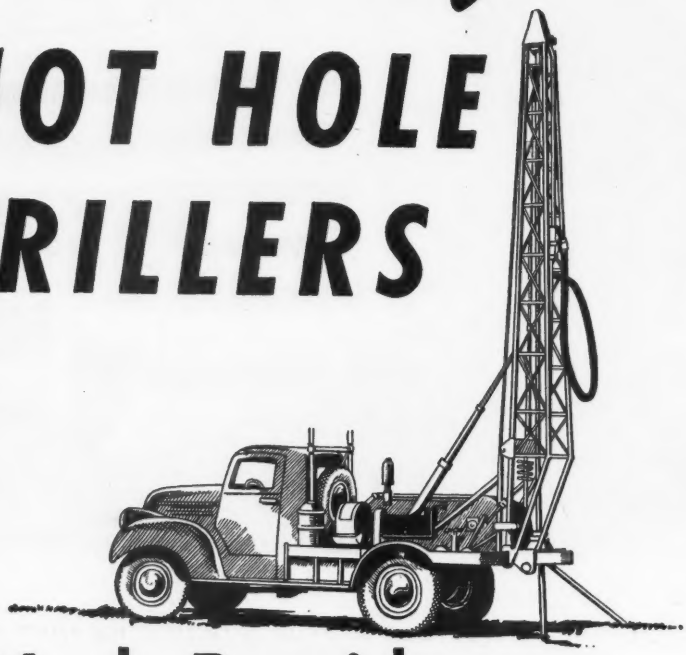

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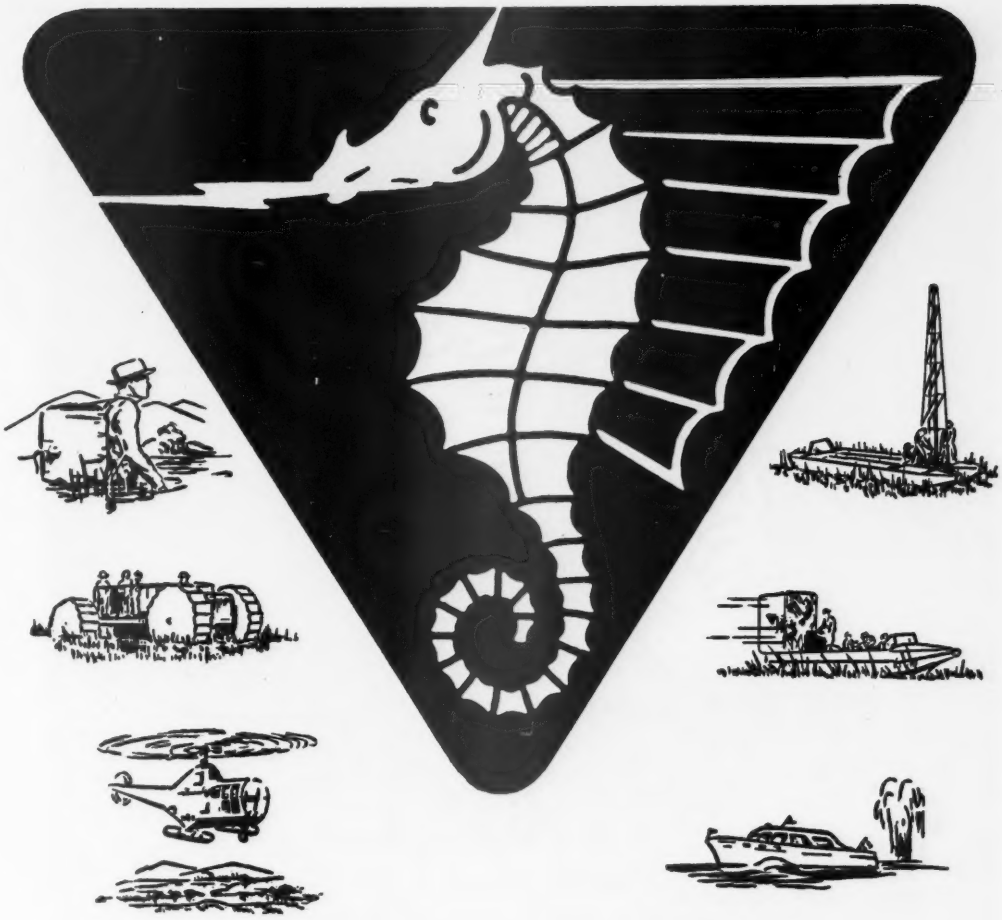

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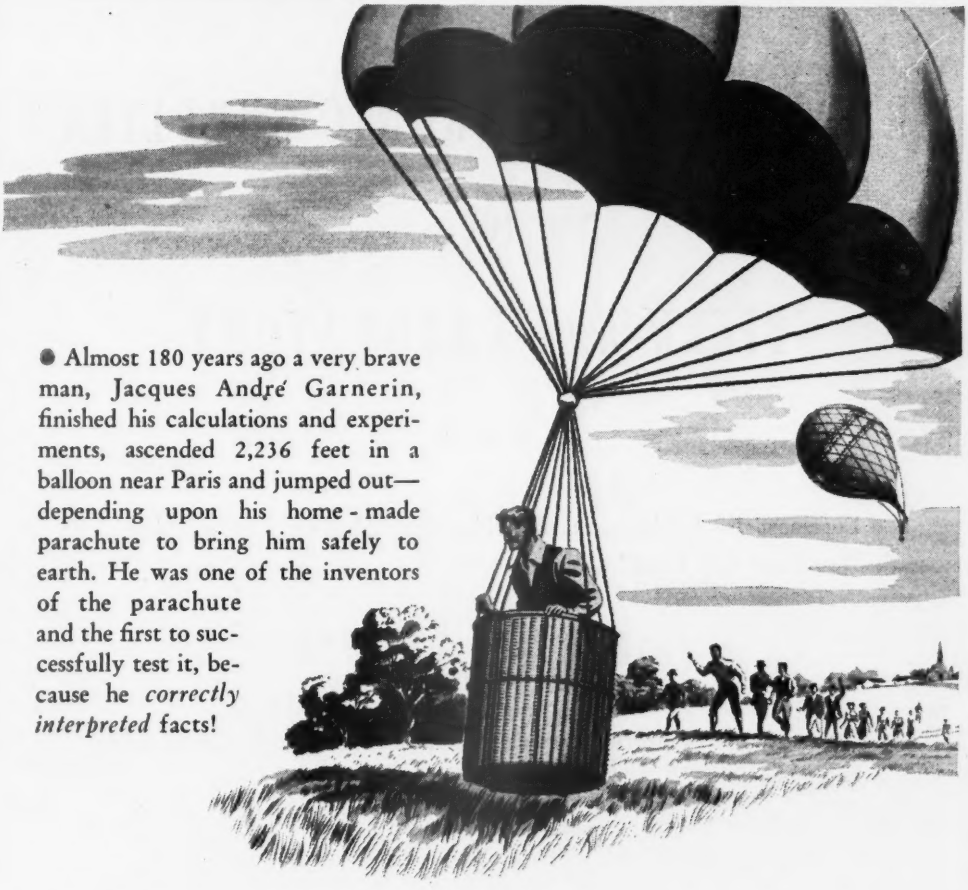

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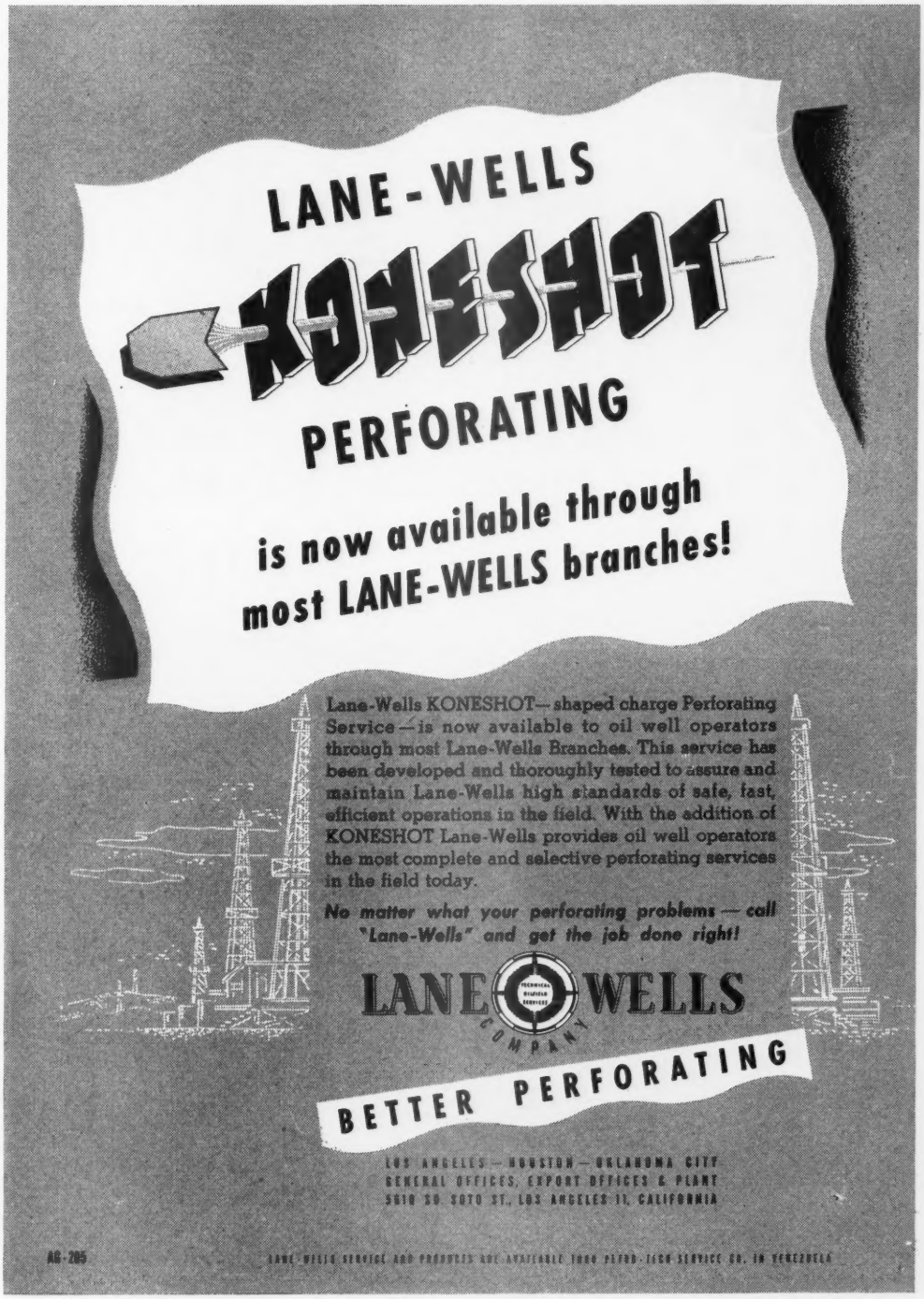
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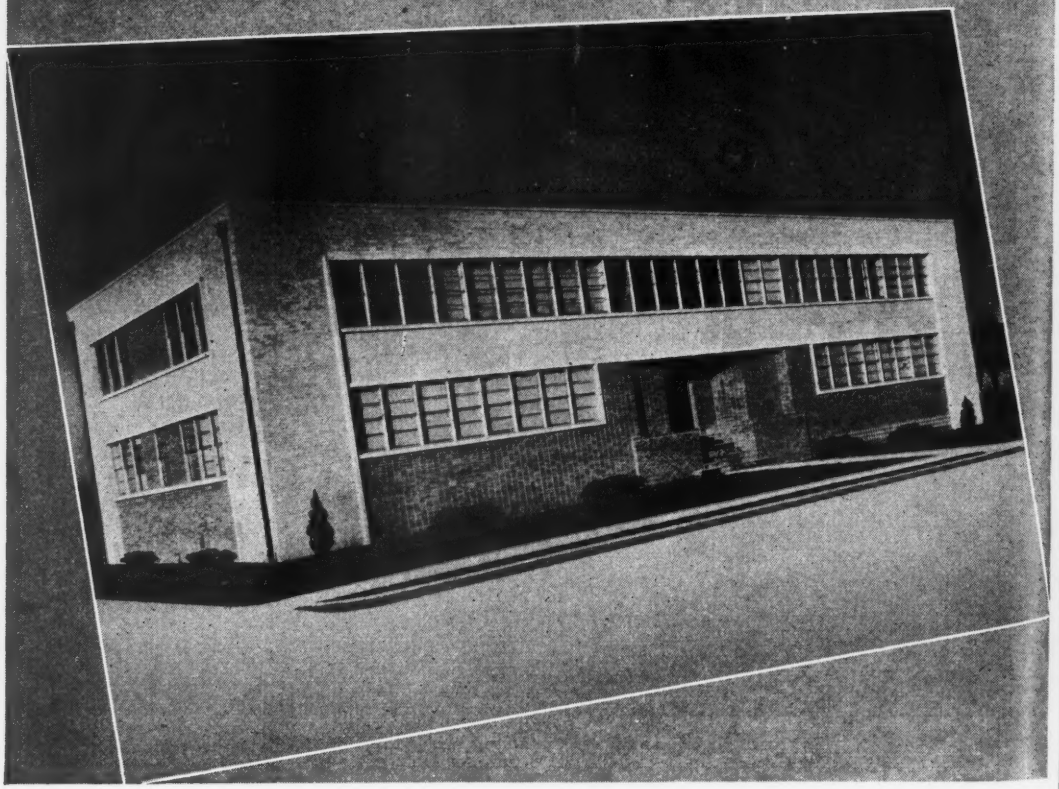

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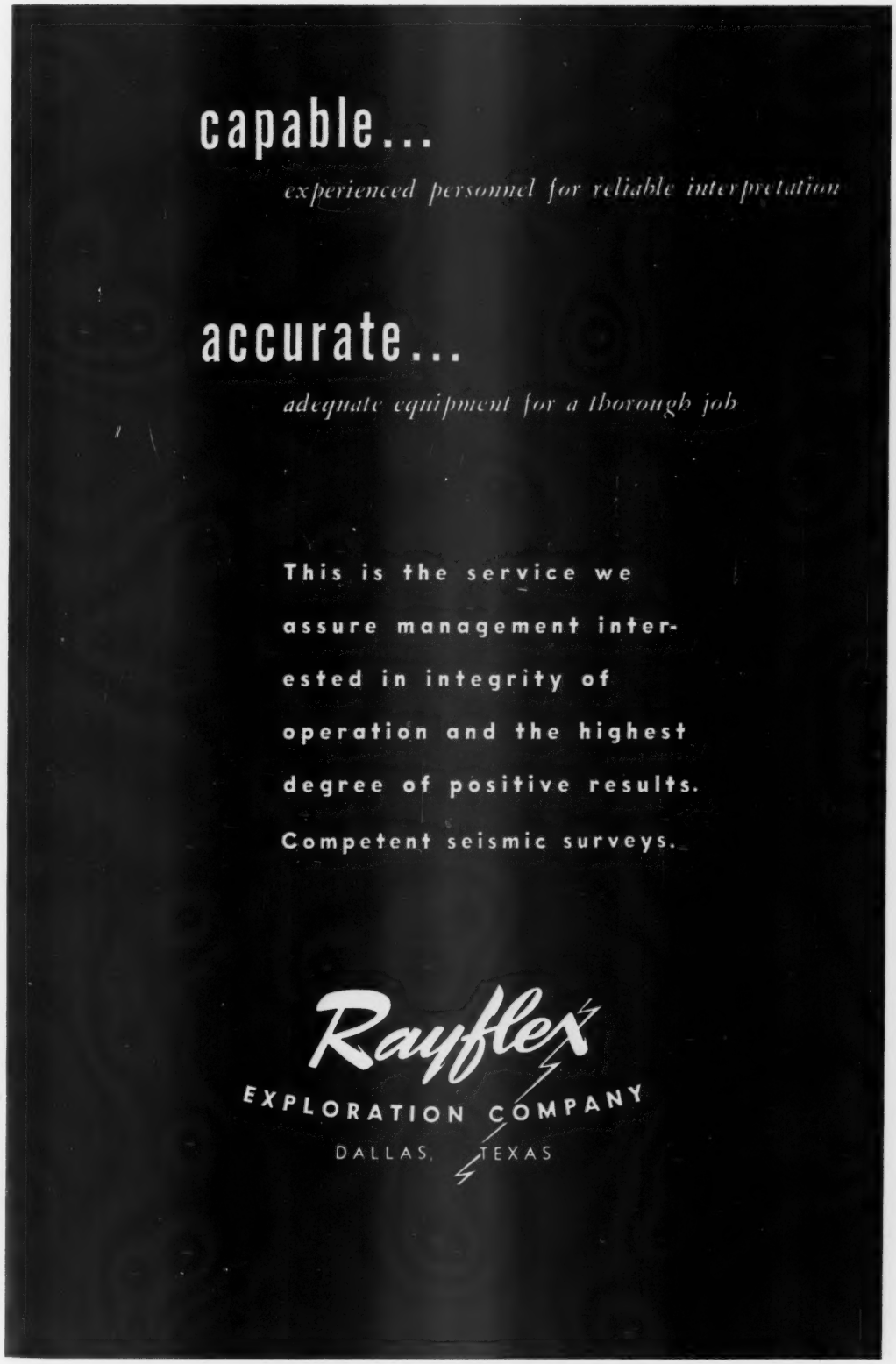
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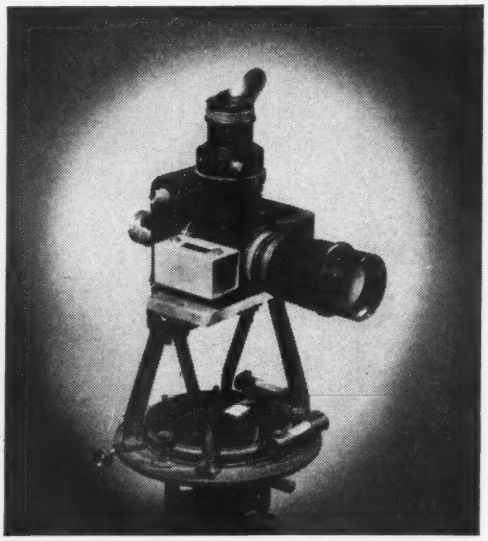

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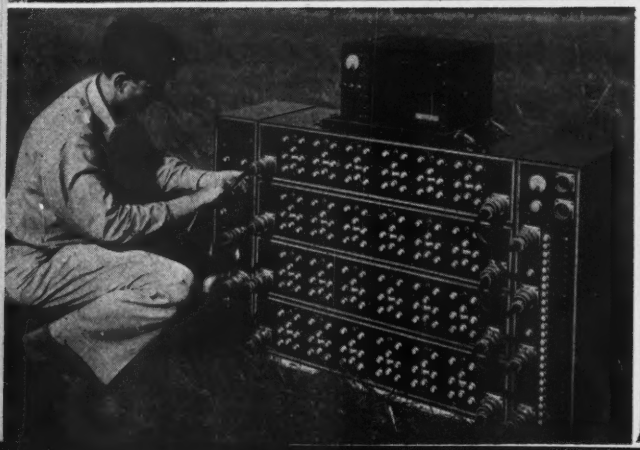
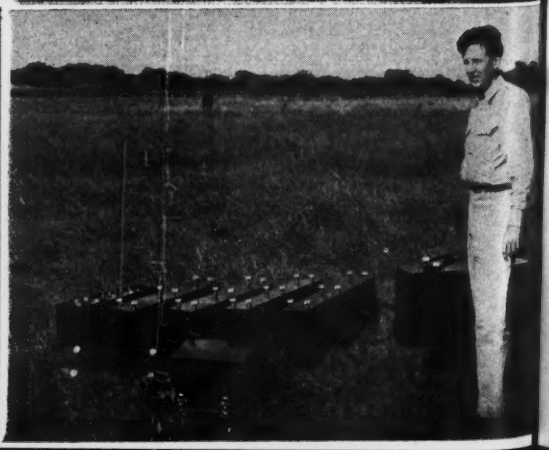
To transport the instruments manually, it is only necessary to disconnect the cables, fasten the water-tight cover on each case, and carry them away.





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AUTOMATIC GAIN CONTROL (AGC): In each channel, a complete automatic gain control regulates the gain by means of a passive network, which does not create any control surge in the amplifier signal circuit. The AGC time constants have been designed to allow strong reflected energy to stand out above the average record level. The AGC may be made inoperative by means of a switch on the front panel of the control unit.

INITIAL SUPPRESSION: If desired, the amplifier gain may be initially reduced before the first breaks, by means of a separate circuit which can be used independently or in conjunction with the AGC. This feature is useful in reducing cross feed from leaky cables and in "Dressing up" the front end of a record. With the AGC turned off, the initial suppression may be set for a straight expansion type record, which can be of great assistance to the geophysicist when entering a new area.

FILTER SYSTEM: A two-section, High-Pass, inductance-capacitance type filter eliminates low frequency disturbance. Frequency selection and the choice of one or both sections are provided by switches on the front panel. A single section Low-Pass inductance-capacitance type filter eliminates high frequency disturbance. Its frequency may also be selected from the front panel.

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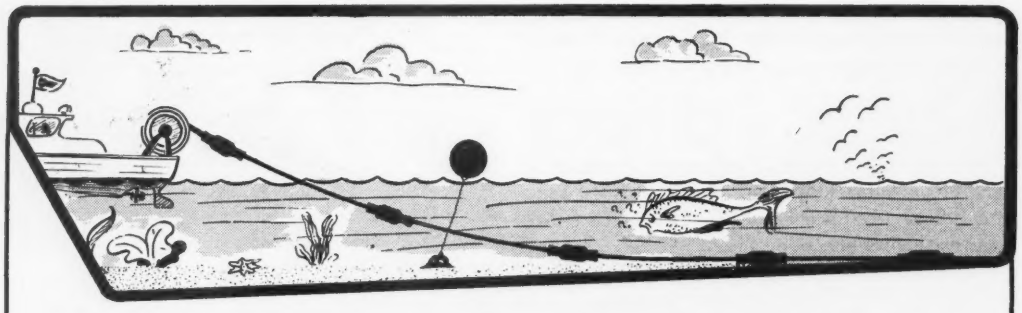

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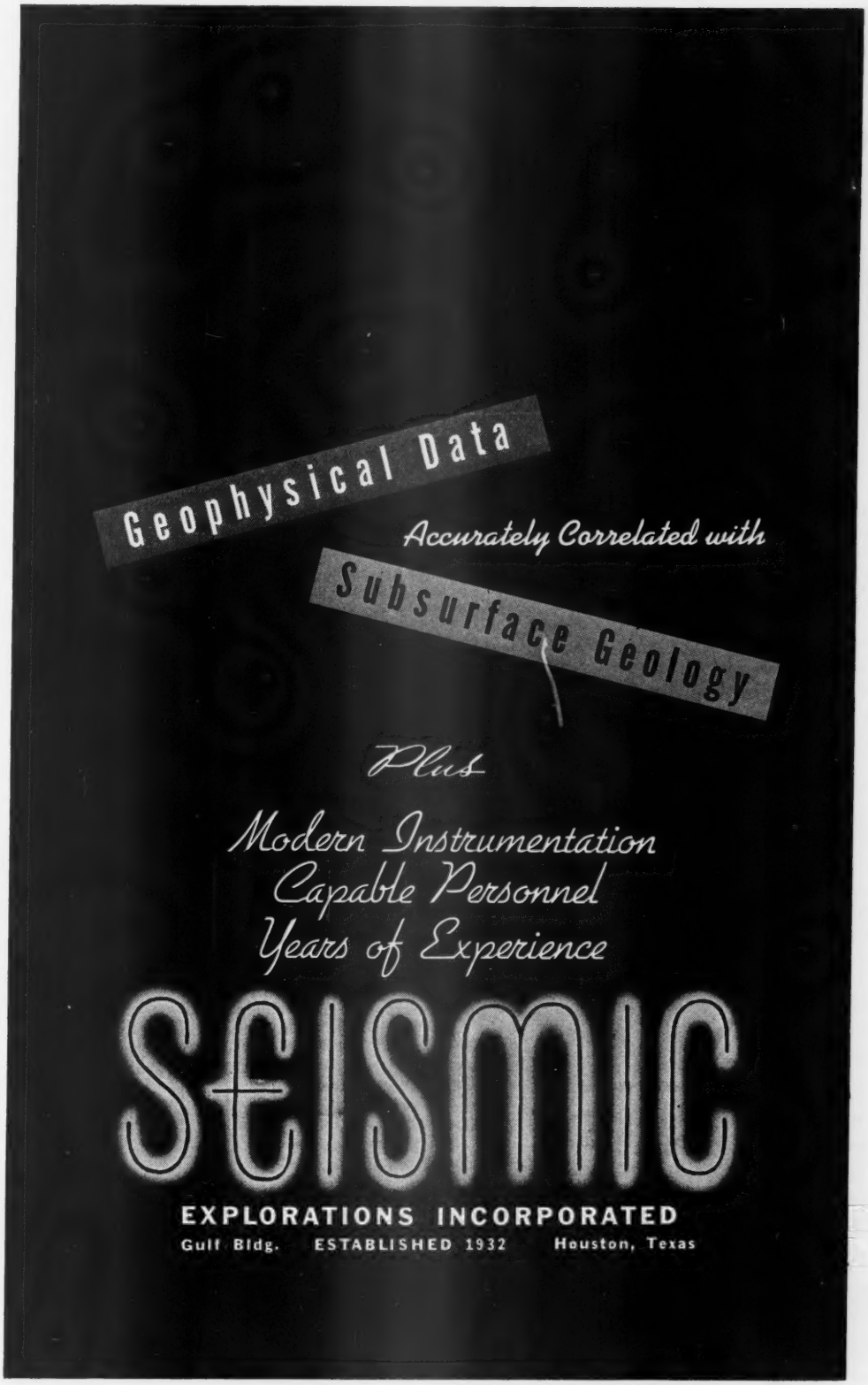
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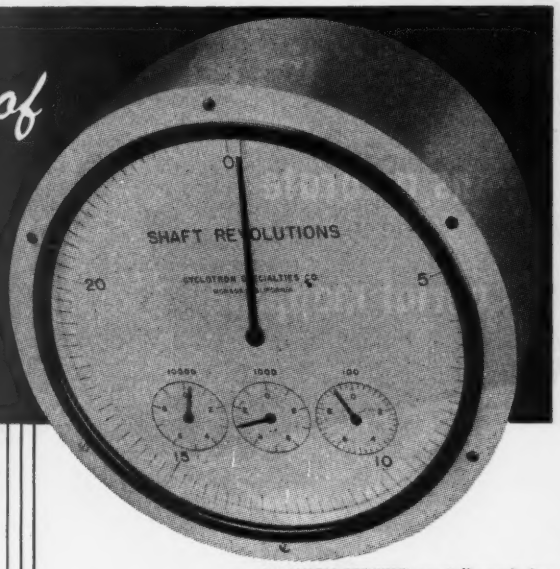

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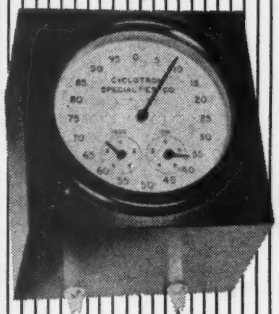

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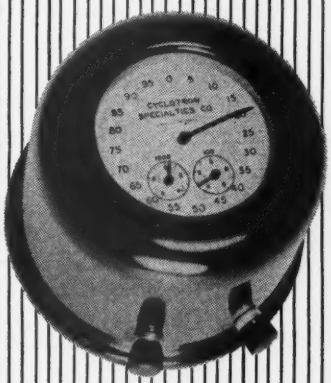

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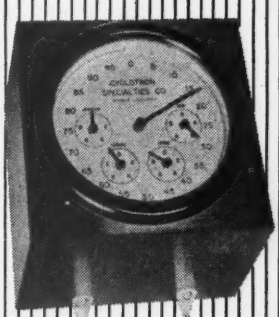

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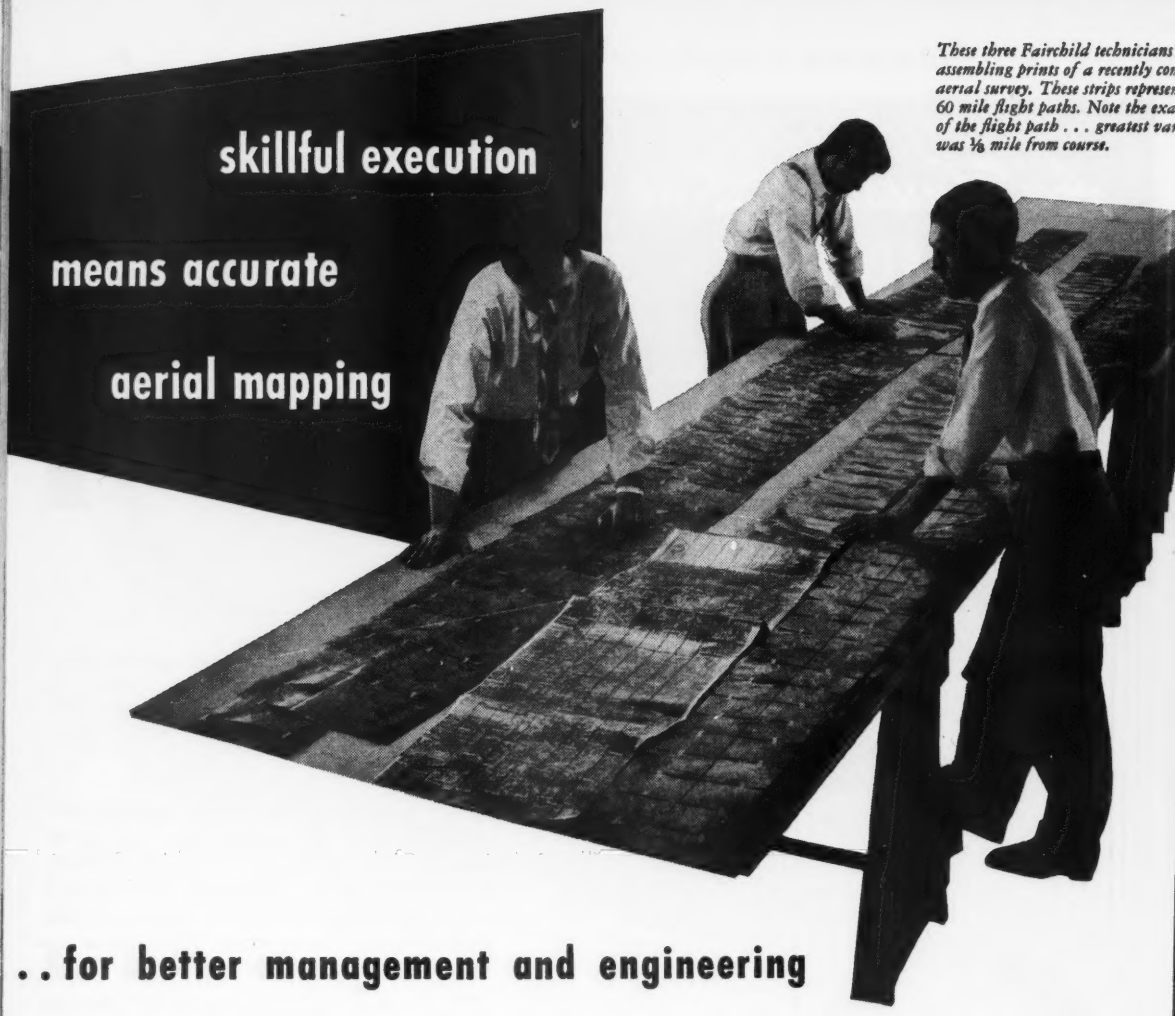

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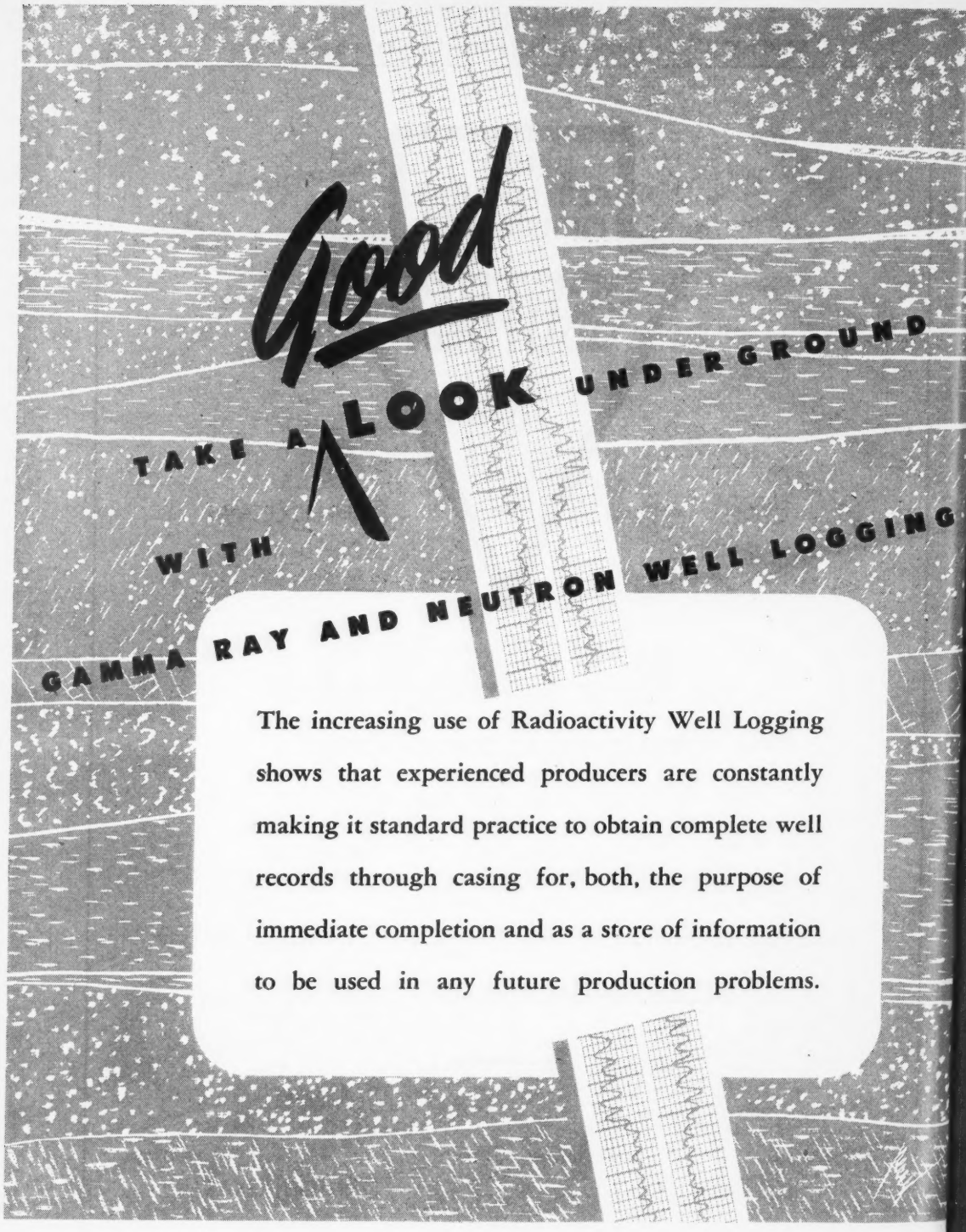

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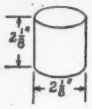

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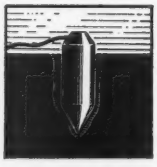
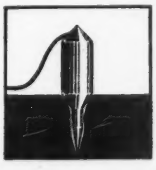
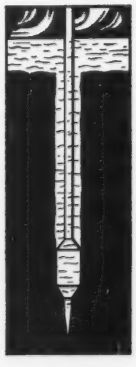
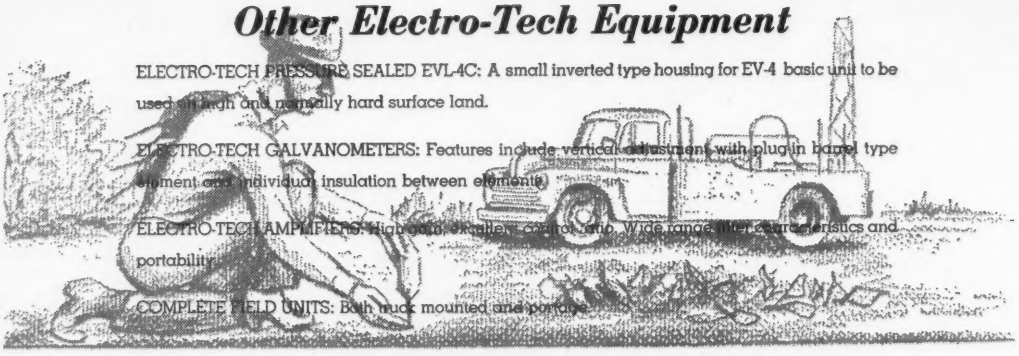






Other Electro-Tech Equipment



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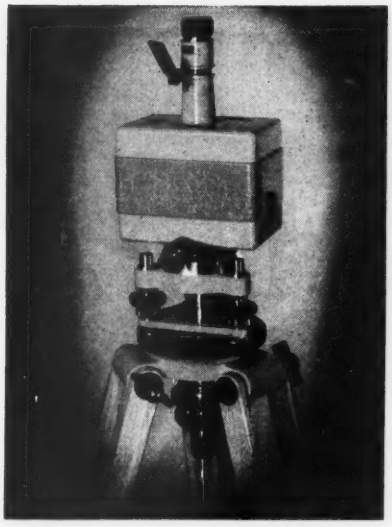

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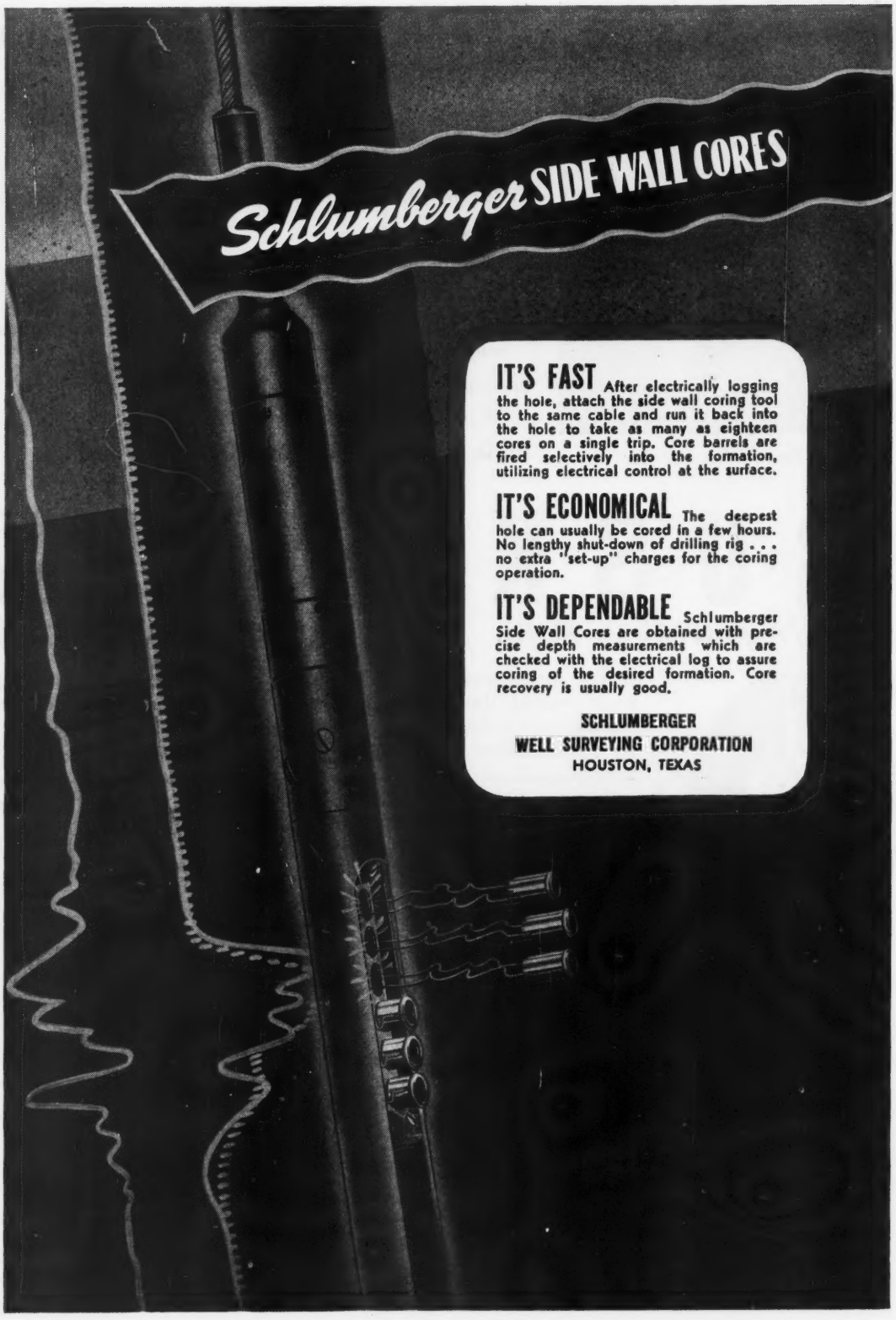
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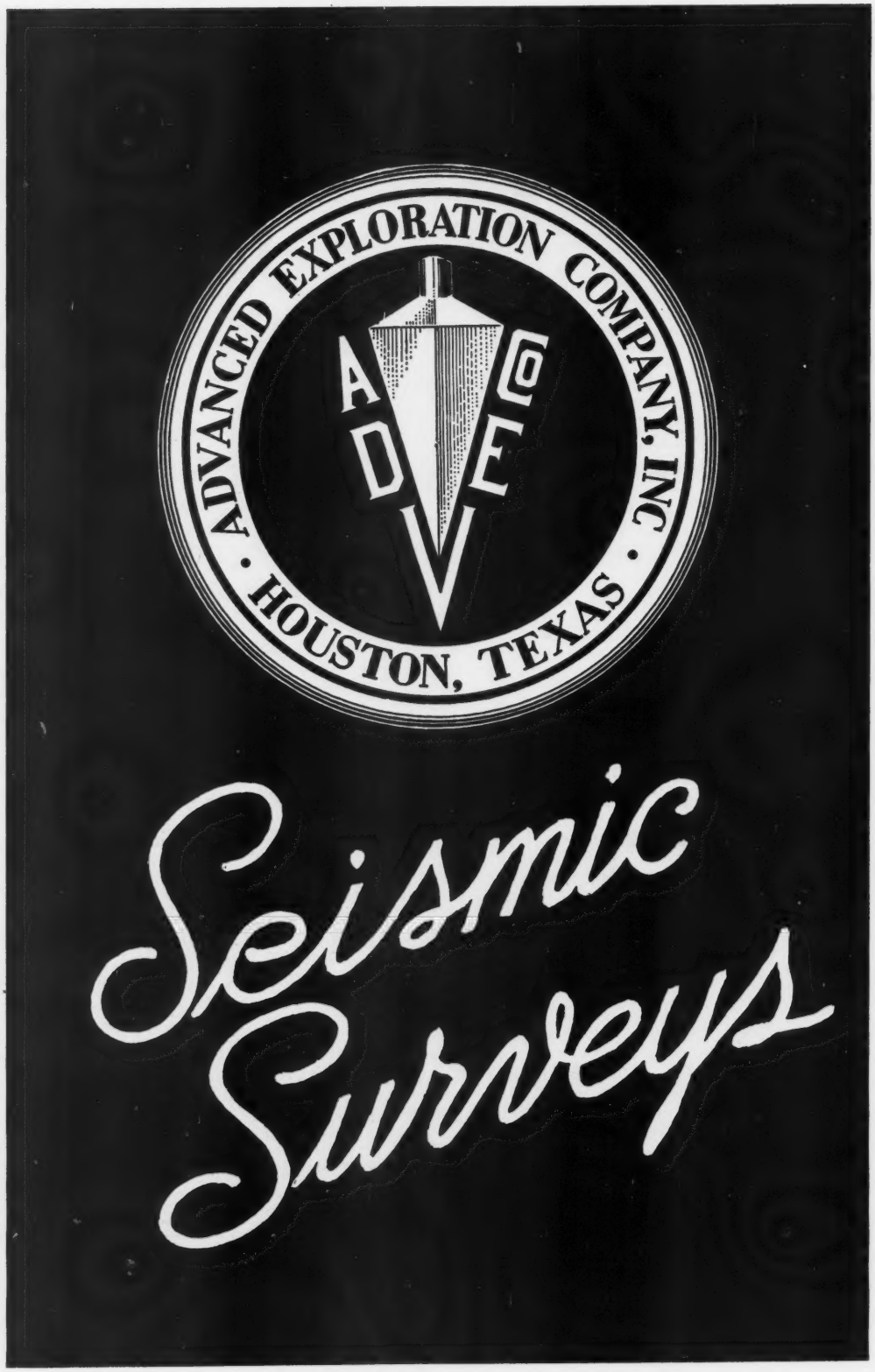
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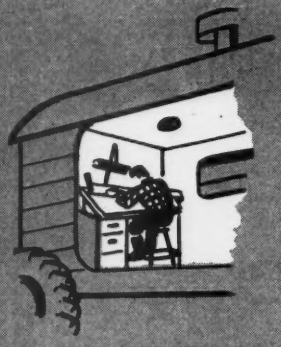

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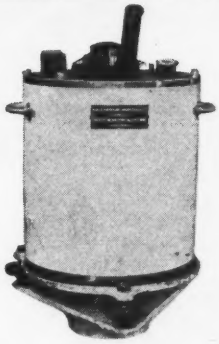

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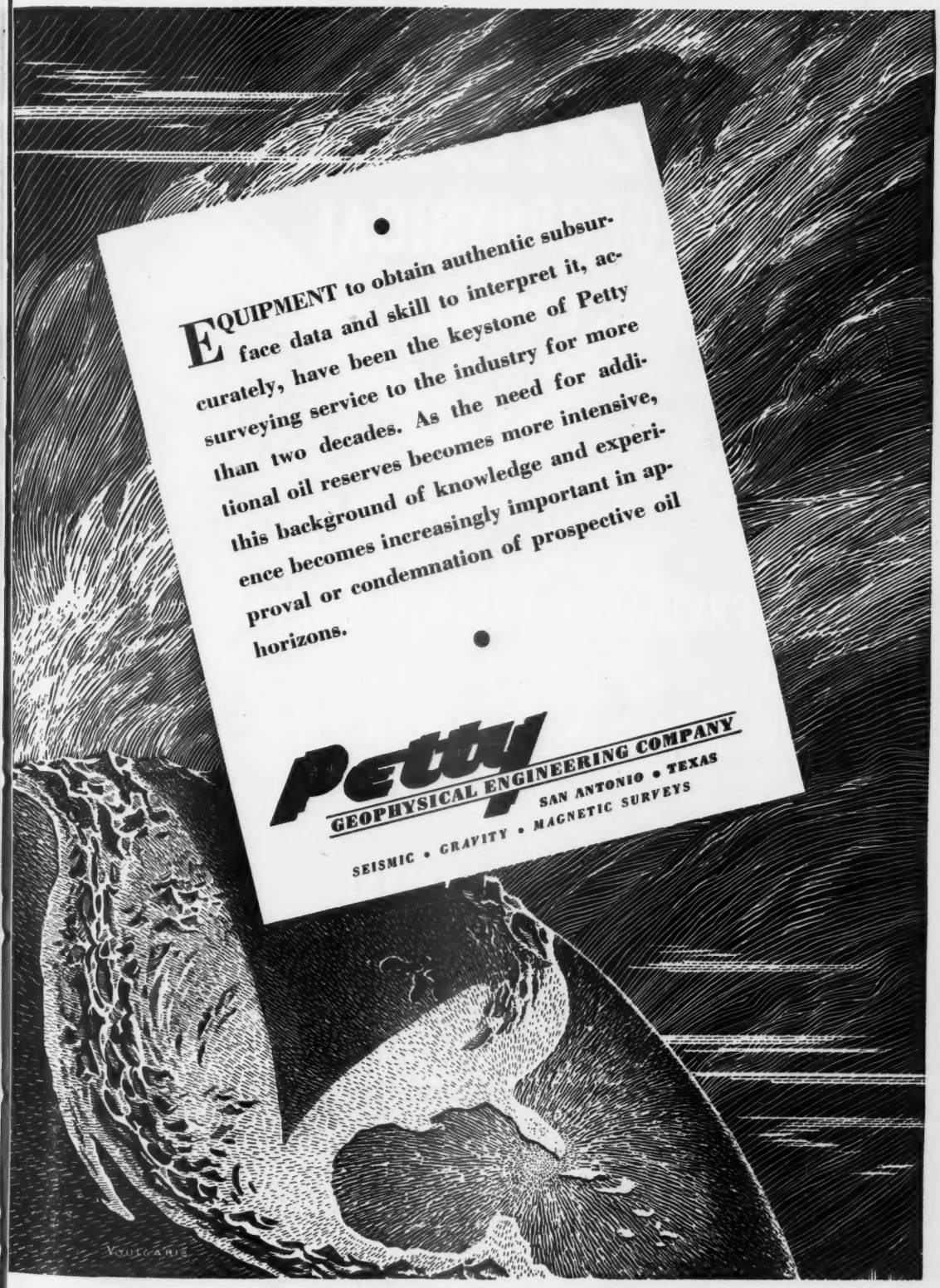
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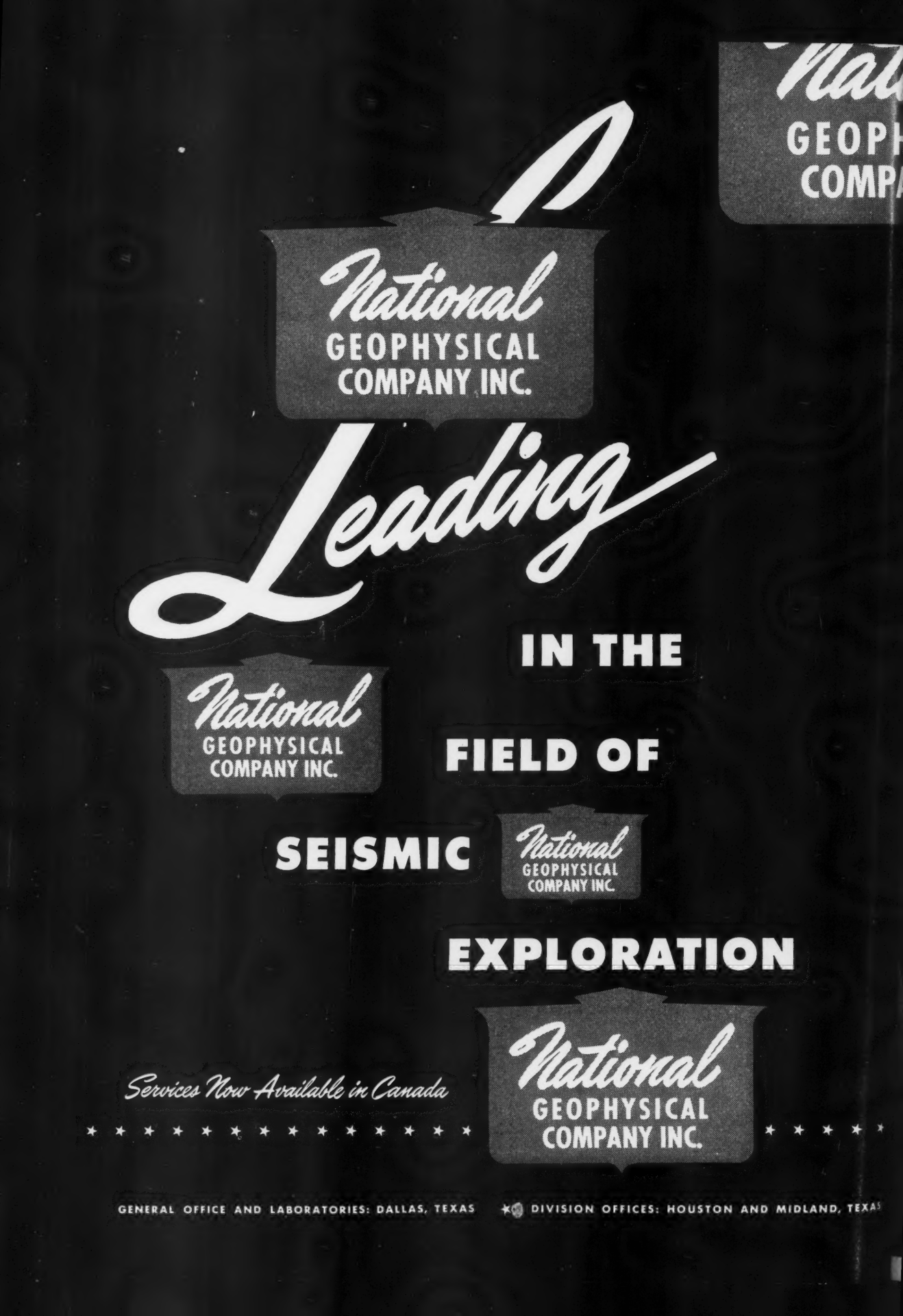
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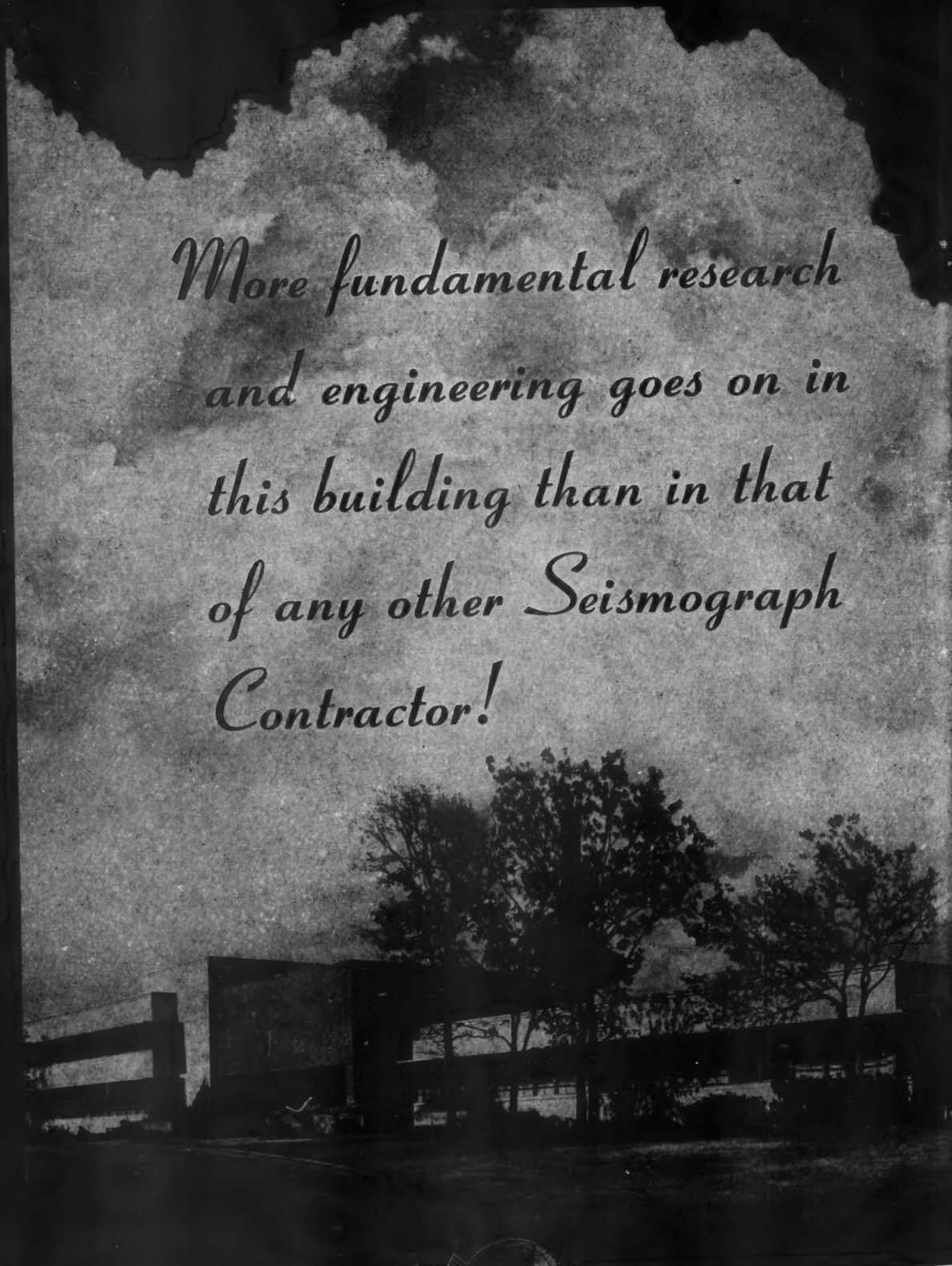

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